Goddard Earth Sciences and Technology Center (GEST)

Fourth Annual Report

31 May 2004

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INTRODUCTION

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INTRODUCTION

Publication of this annual report marks the completion of the fourth year of operation of the Goddard Earth Sciences and Technology (GEST) Center. Progress continues in establishing GEST as a prominent center for research and international collaboration in the Earth sciences and related information technologies. The organization continues at a steady state of approximately 120 researchers and with moderate changes to the administrative staff. The breadth of research interests has continued to grow, necessitating the increase to eight research groups, each composed of scientists with related and complementary expertise. Formation of these groups has also provided the structure needed to efficiently manage the organization. Several new projects established during the previous year, are becoming more mature in providing exciting opportunities for outreach.

Research Accomplishments

Research by GEST faculty and staff has been recognized through significant publications in professional journals, invited presentations, and awards. The main body of this report contains brief discussions of the research focus and results for the faculty and staff who form GEST. The report consists of a total of 114 articles contributed by GEST's faculty researchers and visiting fellows. Also included in each report are the names of GSFC collaborators, accomplishments during the past year, and a plan for next year's work. Cumulative lists of publications in professional journals, conference proceedings papers, etc., are collected in appendices. During this year, there were 175 refereed scientific papers that were authored by GEST faculty and either accepted by or published in major journals. In addition, two GEST senior research faculty members served as lead editors for monographs published by the American Geophysical Union.

Most of the research activities in this volume are funded through the program budgets of collaborating civil servant scientists at Goddard Space Flight Center (GSFC). However, an increasing number of GEST researchers have been successful in submitting proposals to NASA and other agencies, and have been awarded funding for their own research projects. Reports of these grant-funded activities are also found in this report, organized by grant number within each research group. In some cases, GSFC scientists are listed as co-investigators with GEST PIs. GEST members were involved in submission of 106 proposals in the past year, of which 87 were funded; these are also listed in an appendix.

Goddard Visiting Fellows Program in the Earth Sciences

The Goddard Visiting Fellows Program in the Earth Sciences continued into its fourth year with 11 prominent international researchers participating in the program during the reporting period. This program provides the opportunity for selected Ph.D.-level scientists to pursue independent research in collaboration with scientists in the laboratories within the Earth Sciences Directorate either at GSFC or at the Goddard Institute for Space Studies. This report contains a more complete description of the program, the fellows selected, and some of their accomplishments.

The GEST Visiting Scientist Seminar Series continued into its second year. The purpose of these monthly seminars was to provide a forum for the exchange of ideas and results of scholarly research for the NASA research and academic communities associated with the Earth and information sciences disciplines. The seminar speakers were usually one of the prestigious Goddard Visiting Fellows who provided a lecture reflecting their individual research results over a wide range of contemporary scientific topics of high interest. During the past year, the seminar location alternated between the UMBC campus and GSFC, with the presentation site selected to reflect the interests of the local scientific community.

Summer Educational Programs and Graduate Fellowships

The Summer 2003 Educational Programs continued into their third year under GEST management. Despite financial constraints and the loss of the Goddard Coastal Research Fellowship Program, all

programs were successful and provided invaluable experiences to the students. The GEST Center organized and conducted the following three educational programs at GSFC:

- The *Visiting Student Enrichment Program (VSEP),* hosted 18 students in the physical sciences, mathematics, and computer science from high school through graduate school, who participated over a 10-week period in a wide variety of productive projects with GSFC-based mentors;
- The *High Performance Computing (HPC)* summer program hosted fifteen advanced graduate students who were guided through techniques for working with supercomputers on large, illustrative, computation-intensive problems;
- The *Graduate Student Summer Program (GSSP)* played host to twelve students who worked with GSFC-based scientist mentors. The 2003 alumni project reports are available as PDF files at: http://gest.umbc.edu/student_opp/2004_gssp.html. In association with the latter program, a series of four, half-day seminars, entitled, "Measurements and Modeling of Aerosols, Clouds, and Radiation", was conducted. Eight internationally recognized speakers presented seminars that stimulated thought and discussion amongst the students, researchers, and other interested participants. The *Goddard Coastal Research Fellowship Program*, initiated the previous year, was absorbed by GSSP this year, enabling students to be placed at any of the three Goddard institutions: Goddard Space Flight Center, Goddard Institute for Space Studies, and the Wallops Flight Facility.

The educational aspect of GEST activities also included the appointment of two GEST graduate fellows, one in the Physics Department at UMBC and one in UMBC's Department of Computer Science and Electrical Engineering.

Short-Term Visiting Scientist Program and International Workshops

As part of our cooperative research program with the Earth Sciences Directorate, GEST facilitates collaboration between scientists based at GSFC and in organizations outside the Center who must work for short periods at GSFC, at field research locations, or at external conference sites. In this report you will find lists of U.S. and international scientists and their collaborating organizations that were assisted by the GEST administrative staff. Over 50 visitors participated in this program from U.S. universities and international federal laboratories and universities.

Global Energy and Water Experiment

A major new focus of the GEST Center involves supporting NASA Earth Science Program objectives through exploiting the opportunities for promoting coordination of broad international environment-related research within the framework of NASA/UMBC cosponsored activities. Such an opportunity developed over the past year with respect to the Global Energy and Water Experiment (GEWEX), an element of the World Climate Research Programme sponsored by the World Meteorological Organization, the International Oceanographic Commission of UNESCO, and the International Council of Scientific Unions. GEWEX represents the most ambitious attempt to characterize, understand, model, and predict the behavior of the critical roles of water and energy in the Earth's climate system. For example, improved knowledge of the availability of fresh water is of extreme importance to food production and human health worldwide. Climate is a major factor affecting the distribution of water resources, and GEWEX has been designed to help provide a reliable scientific basis for establishing sound environmental policy.

In April 2003, NASA approved a UMBC proposal to assume responsibility for administering the International GEWEX Project Office (IGPO) within the structure of its GEST Center. The IGPO will be responsible for international coordination of all aspects of GEWEX with the worldwide scientific community and the space agencies. Details about GEWEX may be found on its website:

http://www.gewex.org. An international search resulted in the appointment of Richard Lawford as director of the IGPO and as a UMBC senior research scientist in GEST.

The IGPO has coordinated the preparations for the GEWEX Scientific Steering Group meeting in Morocco, both in terms of providing briefings and written material, and in developing strategies to implement recommendations from the meeting. The IGPO has also been active in establishing the programmatic structure, and organizing resources and people for the Fifth International GEWEX Conference to be held in Orange County, California in 2005.

Involvement of Consortium Members

The contributions of our four consortium partners continue to be significant. Most of the collaborative researchers in GEST were faculty of UMBC. However, the number of researchers at Hampton University, Howard University, and Caelum Research Corporation increased during this fourth year of GEST. Northrop Grumman Corporation has provided invaluable advice and support through representation on the GEST Executive Board.

Acknowledgements

The quality and significance of the research conducted by GEST and its collaborators is extremely satisfying. We have been especially happy to witness the realization of goals that were imagined during the inception of GEST, having to do with educational programs, support to graduate students and post-doctoral investigators, providing opportunities for visiting fellows, focused-topic international workshops, and international program coordination. Those activities will grow in importance, as the GEST capabilities become more widely known in the Earth sciences community.

GEST's continued growth and contributions have been possible only because of the hard work and enthusiastic support of many people. As always, the real credit for the vitality of the organization goes to the GEST faculty and staff whose excellent work is represented within. I am also grateful to Drs. Ronald Errico, Susan Hoban, Peter Merheim-Kealy, Richard Judelson-Kelley, Oreste Reale, Chung-Lin Shie, and Lin Tian, whose innumerable contributions as research group leaders greatly contributed to the progress made in this fourth year. Recognition for the development of this and the previous year's annual reports is given to the leadership of Dr. Tom Low and his collaboration with all the research group leaders. His work on this report and that of the research groups' leaders is greatly appreciated. Recognition for the day-to-day operations of GEST is given to Ms. Anathea Brooks. Her many organizational skills, attention to detail, and inexhaustible energy have inspired us to successfully complete this fourth year.

We would like to thank Dr. Mitchell K. Hobish, who served as scientific editor of this volume, which required carefully editing, integrating, and formatting the many pieces and contributions into a single consistent document; Ms. Vanessa McNeill and Ms. Heidi Harting-Rex for the detail work of copyediting; and Ms. Lisa Richard, for performing the layout of this document. Ms. Carroll Ann Susco, Publications Coordinator at the American Geophysical Union, was of great aid in guiding the production team through the complexities of formatting the bibliographic material.

I continue to be indebted to the UMBC administration—especially to Dean Scott Bass, for his support and guidance—and to the administration of the NASA Goddard Space Flight Center—especially Dr. Franco Einaudi, for his vision of GEST for which we continue to strive.

Robert J. Curran
Director

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TABLE OF CONTENTS

INTRODUCTION ..... **iii**

EXECUTIVE SUMMARY **1**

GLOBAL MODELING AND ASSIMILATION OFFICE RESEARCH GROUP A **5**

Task 910-01-008: Chemical Data Assimilation 9
David Lary

Task 910-05-082: Reanalysis for Stratospheric Tracer Studies 10
Shuhua Li

Task 910-08-099: Improvement of the Physical Parameterizations in the Finite-Volume General Circulation Model 11
Jiun-Dar Chern

Task 910-14-123: The Impact of ENSO on Extreme Winter Weather of the Continental United States 13
Yehui Chang

Task 910-19-135: Studies of Tropospheric Ozone in the GMAO Satellite Ozone Assimilation System 14
Hiroo Hayashi

Task 910-31-155: Goddard Earth Observing System Data Assimilation System 15
Ronald M. Errico

Task 971-00-002: Parameterized Physics Development for Global Modeling and Assimilation Office Atmospheric Model 17
Julio T. Bacmeister

Task 971-00-002: Physical Parameterization Studies for NASA's Seasonal-to-Interannual Prediction Project Atmospheric Model 18
Myong-In Lee

Task 971-00-002: Parameterized Physics Development for Global Modeling and Assimilation Office Atmospheric 20
Sarith Mahanama

GLOBAL MODELING AND ASSIMILATION OFFICE RESEARCH GROUP B **23**

Task 900-00-002: Soil Moisture and Land Hydrology: Postdoctoral Visiting Appointment 27
Sonia I. Seneviratne

Task 910-01-008: Treatment of Atmospheric Trace Constituents in the Finite-Volume Data Assimilation System 28
Steven Pawson

Task 910-01-009: Cloud Assimilation 30
Peter M. Norris

Task 910-01-010: Satellite Data Group Leader 32
Lars Peter Riishojgaard

Table of Contents (continued)

Task 910-08-099: Synoptic-Dynamic Evaluation and Improvement of the NASA Finite-Volume General Circulation Model 33
Oreste Reale

Task 910-14-124: Rainfall and Cloud Assimilation 35
Xin Lin

Task 910-14-125: Development of a Next-Generation Finite-Volume Dynamical Core on Geodesic Grids 36
Kao-San Yeh

Task 971-00-002: Interdecadal Variability of Precipitation in the Americas and Africa 36
Rosana Nieto Ferreira

Task 971-00-002: Land Data Assimilation in Support of NASA's Seasonal-to-Interannual Prediction Project 38
Rolf H. Reichle

Task 971-00-002: Ocean Data Assimilation in a Global Ocean Circulation Model 39
Task 974-03-070: Snow Data Assimilation in a Land Surface Model
Chaojiao Sun

Task 971-00-002: NASA Seasonal-to-Interannual Prediction Project: Study of Predictability and Forecast of the ENSO Phenomenon 41
Augustin Vintzileos

CLOUD MODELING RESEARCH GROUP 43

Task 912-02-027: Analysis of Dual-wavelength Doppler Radar Measurements: Retrieval of Rain Drop Size Distribution and Attenuation 47
Lin Tian 47

Task 912-02-029: Application of Satellite Observations, Numerical Modeling, and Data Assimilation to Understand and Predict Mesoscale Precipitation Systems 48
Zhaoxia Pu

Task 912-02-036: Physics of Cirrus Clouds and their Role in Global Climate 49
Ruei-Fong Lin

Task 912-10-109: Various Numerical Applications to Tropical Convective Systems Using a Cloud-Resolving Model 51
Chung-Lin Shie

Task 912-10-116: Multi-Day Cloud-Resolving Modeling Studies of Tropical and Midlatitude Convective Systems 52
Daniel Johnson

Task 912-18-129: Study of Tropical Cyclone Activities 54
Liguang Wu

Task 912-19-131: Cloud Radar Calibration, Data Analysis, and Instrument Development for Studies of Hurricane Genesis 55
Lihua Li

Table of Contents (continued)

Task 912-21-140: Precipitation Estimation from Satellite Active and Passive Microwave Observations 57
Mircea Grecu

Task 912-21-145: Tropical Rainfall Measuring Mission Project Science 59
Guojun Gu

Task 912-23-147: Global Precipitation Mission Physical Radiative Transfer Model 60
Kwo-Sen Kuo

Task 912-29-152: Impact of Aerosols On Midlatitude and Tropical Storms: A Model Study 61
Xiaowen Li

Task 912-29-152: Development of the Second-Generation Goddard Cumulus Ensemble Model 63
Xiping Zeng

NASA Grant: Organization, Structure, and Evolution of Tropical Convection and Their Environment (CV525890) 64
Jian-Jian Wang

CLOUD ANALYSIS RESEARCH GROUP 67

Task 912-01-012: Development of Advanced Electro-Optic Instrumentation and Technologies for Earth and Climate Monitoring 71
Reginald S. Lancaster

Task 912-06-088: Space-Borne Lidar Studies of Polar Clouds and Climate 72
Ashwin Mahesh

Task 912-31-157: Analysis of Scattering Properties of Eccentric Spheres in Application to Lidar Measurements 74
Igor Veselovskii

Task 912-52-202: The Micro-Pulse Lidar World-wide Observational Network 76
Timothy Berkoff

Task 913-12-117: NASA Seasonal-to-Interannual Prediction Project: Effects of Extra-Tropical Air-Sea Interactions on Predictability of Warm Season Precipitation Anomalies over the United States 77
Hailan Wang

Task 913-12-117: Modeling and Diagnosis of Asian Climate: Impact of SSTs and Aerosols 79
Fanglin Yang

Task 913-48-190: Atmospheric Solar Radiative Transfer 80
Guoyong Wen

Task 924-21-142: (a) Water Vapor and Cloud Detection Validation for Aqua Using Raman Lidars and AERI; (b) Using Radar, Lidar, and Radiometer Measurements to Classify Cloud Types and to Study Middle-Level Cloud Properties; (c) CloudSat Level 2 Combined Radar and Lidar Cloud Scenario Classification Standard Product Development 82
Zhien Wang

Table of Contents (continued)

Task 971-20-137: Remote Sensing of Sea Surface Salinity 84
Kevin Horgan

Task 975-32-159: A Study of Microwave Rader on Estimates of Hydrometeor Profiles 85
Liang Liao

ATMOSPHERIC CHEMISTRY AND DYNAMICS RESEARCH GROUP 87

Task 900-37-172: Evaluation of Tropospheric Processes in Simulations Using the Global Modeling Initiative Chemical Transport Model 91
Bryan Duncan

Task 910-01-014: Radiative Transfer and Zonally Symmetric Atmospheric Modeling 92
Joan E. Rosenfield

Task 910-04-074: Observationally Based Evaluation of Chemical and Transport Processes in Atmospheric Models....93
Susan Strahan

Task 910-04-074: Assimilation Studies 95
Clark Weaver

Task 913-13-120 and
Task 916-08-101: Calculation of Radiative Forcing of Aerosols and Clouds Using Satellite and *In Situ* Measurements 96
Nai-Yung Christina Hsu

Task 913-18-130: Modeling of Rainfall Statistics from Satellite and Ground-Based Remote Sensing Measurements 97
Prasun K. Kundu

Task 916-01-016: Interactive Global Modeling of Stratospheric and Tropospheric Photochemical Systems Coupled with the Atmospheric General Circulation Model....99
Mohan Gupta

Task 916-01-017: Investigation and Application of the Match Technique 100
Gary A. Morris

Task 916-04-076: Surface UV Irradiance and Aerosol UV Absorption Remote Sensing.... 102
Nickolay A. Krotkov

Task 916-13-121: Climate and Trace Species 104
Eric Bucsela

Task 916-21-144 and
Task 916-43-181: Tropospheric Ozone Derived From Satellite Measurements 106
Jerry R. Ziemke and Sushil Chandra (respectively)

Task 916-37-173: Stratosphere-Troposphere Exchange 107
Mark A. Olsen

Task 916-39-176: Design and Implementation of a Common Chemistry and Transport Model Framework for the Interactive Simulation of Stratospheric and Tropospheric Photochemical Systems.... 108
Huisheng Bian

Table of Contents (continued)

NASA Grants: Solar Irradiance Variability and Climate Implications (NAG5-11326, NAG5-11601, NAG5-11624) 110
Judit M. Pap

TERRESTRIAL PHYSICS RESEARCH GROUP 113

Task 900-03-041: Spectral, Angular, and Vertical Characterization of Aerosols for Radiative Properties 117
Charles K. Gatebe

Task 900-35-168: Remote Sensing Information Support for Public Health Issues in the Arctic.... 118
Boris S. Yurchak

Task 913-13-120: Characterization of Aerosol and Atmospheric Parameters from Spaceborne and Surface-Based Remote Sensing 120
Santiago Gassó

Task 921-01-018: Physical Volcanology, Planetary Geology, and Geophysics 121
Susan Sakimoto

Task 923-03-067: AERONET Ground Based Remote Sensing of Aerosol Optical Properties 123
Oleg Dubovik

Task 923-03-067: AERONET Ground-Based Remote Sensing of Aerosol Optical Properties..... 124
Thomas F. Eck

Task 923-03-067: Analysis of Aerosol Optical Data: Aerosol Robotic Network Ground-Based Remote Sensing of Aerosol Optical Properties..... 126
Norm T. O'Neill

Task 923-03-067: Validation of Total Ozone Mapping Spectrometer Aerosol Products and Comparison with Other Satellite Products 127
Alexander Siniuk

Task 923-03-067: Aerosol Robotic Network Ground-Based Remote Sensing of Aerosol Optical Properties..... 128
Alexander Smirnov

Task 923-06-092: Studies of Earth's Surface Interannual Variability Using Data from Satellites and Distributed Ground Stations 130
Assaf Anyamba

Task 923-32-162: Development of an Advanced Atmospheric Correction Algorithm for Earth Observing System Instruments 132
Alexei Lyapustin

Task 923-32-162: Algorithm Development and Validation for Land Surface and Atmospheric Products for VIIRS 133
Yujie Wang

Task 923-37-170: Visible and Infrared Imaging Radiometer Scanner Validation Technique 134
Mohan Nirala

Table of Contents (continued)

Task 923-39-175: NPOESS Preparatory Project System Calibration/Product Validation Studies 135
Bruce Guenther

Task 923-46-188: National Polar-Orbiting Operational Environmental Satellite System Preparatory Project Algorithms and Data Systems 136
Peter Merheim-Kealy

Task 923-51-194: Integrating Fluxnet-Canada with the North American Carbon Program 137
Hank Margolis

INFORMATION SCIENCE AND EDUCATIONAL TECHNOLOGY RESEARCH GROUP 141

Task 130-05-085: Learning Technologies 145
Susan Hoban, Daniel Laughlin, and Marci Delaney

Task 550-06-087: Steps Toward an Ultraviolet/Optical Fizeau Interferometer 147
Gregory Solyar

Task 588-45-185: Science Goal Monitor: Tools for Science Goal Capturing and Onboard Goal Monitoring 148
Anuradha Koratkar

Task 693-42-179: Data Compression Algorithms Design for LEISA 150
Gregory Solyar

Task 902-00-006: Executive Science/Technology Secretariat Support to NASA-HQ/ESE 151
Sushel Unninayar

Task 930-01-023: Globalization of Regional Atmospheric Models 153
Miodrag Rančić

Task 930-03-068: Science Information Systems 154
Susan Hoban

Task 930-12-115: PARAMESH 155
Kevin Olson

Task 935-01-022: Parallel and Distributed Computing 156
Udaya A. Ranawake

Task 935-16-127: Automatic Registration of Multi-Sensor and Multi-Temporal Remotely Sensed Imagery 157
Harold Stone

Task 935-19-124: Automatic Registration of Multi-Sensor and Multi-Temporal Remotely Sensed Imagery 159
Ilya Zavorin

HYDROLOGICAL SCIENCE RESEARCH GROUP 161

Task 971-20-137: Aquarius Sea Surface Salinity 165
S. Daniel Jacob

Task 971-26-149: Early Spring Bloom in the North Atlantic Associated with NAO-Induced Long-Term Oceanic Circulation Changes 167
Ken-ichi Mizoguchi

Table of Contents (continued)

Task 971-32-161: Air-Sea-Ice Interaction 168
Yunhe Zhao

Task 972-21-143: Advanced Laser Fluorescence Technologies for Oceanic Biomonitoring 169
Alexander M. Chekalyuk

Task 972-37-169: Empirical Algorithm Refinement for TOPEX/Poseidon and Jason Altimeter Sea-State Bias Range Correction by Using Operational Global Wave Model Data 171
Hui Feng

Task 974-03-070: Coordinating and Implementing NASA Global Water Cycle Research 172
Deborah Belvedere

Task 974-03-070: (a) Coupling High-Resolution Earth System Models Using Advanced Computational Technologies; (b) A Catchment-Based Global River Routing Scheme for Climate Models and Assimilation of Streamflow and Altimetry Data 173
Joseph L. Eastman

Task 974-03-070: Global Land Data Assimilation System 174
Jonathan Gottschalck

Task 974-03-070: Global Land Data Assimilation 176
Urszula Jambor

Task 974-03-070: Land Information Systems 177
Sujay V. Kumar

Task 974-03-070: Global Land Data Assimilation System 179
Jesse Meng

Task 974-03-070: (a) Optimal Land Initialization for Seasonal Climate Prediction (b) The Effect of Subgrid Variability of Snow Cover in Vegetated Regions on Land-Atmosphere Interactions 180
Wenge Ni-Meister

Task 974-03-070: Coordinating and Implementing NASA Global Water Cycle Research 181
C. Adam Schlosser

Task 974-05-086: Calibration and Validation of an Algorithm for Retrieving Snowpack Parameters at Global-to-Regional Scales Using NASA's Aqua Satellite Remote Sensing Instruments 183
Richard E.J. Kelly

Task 974-44-183: Operational Modeling of Soil Moisture at Local and Regional Scales 184
Yihua Wu

Task 974-44-184: Land Information System 186
Yudong Tian

Task 974-52-197: (a) Global Validation of EOS-Aqua Land Surface Dynamics using Data Assimilation (b) HYDROS Risk Reduction Research Activities 187
Xiwu Zhan

Table of Contents (continued)

Task 974-52-198: Quantify the Errors in Passive Microwave Snow Water Equivalent Estimates, and Assimilate the Remotely Sensed Snow Products into the NASA NSIPP Land Surface Model 188
Jiarui Dong

Task 974-52-199: The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and Forecasting for Water Resources Management in the Columbia River Basin 190
Kristi Arsenault

Task 974-52-199: Water Resources Management Research Coordination 192
Jonathan M. Triggs

GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (GEWEX) 193

Task CV526590: International Global Energy and Water Cycle Experiment Project Office 195
Richard Lawford

GODDARD VISITING FELLOWS PROGRAM IN THE EARTH SCIENCES 197

Task 900-37-172: Modeling Heterogeneous Chemistry 201
Susanne E. Bauer

Task 900-37-172: Forest Characterization and Inventory 202
Warren B. Cohen

Task 900-37-172: Phytoplankton Biomass, Primary Production, and Surface Dynamics from Ocean Color Sensors in the Southwestern Atlantic and Southern Oceans 203
Carlos Garcia and Virginia M.T. Garcia

Task 900-37-172: Time-Variable Gravity from Ground to Satellites and its Relation to Global Geodynamics 205
Jacques Hinderer

Task 900-37-172: Goddard Visiting Fellow 207
Roger H. Lang

Task 900-37-172: Development of Comprehensive Antarctic Magnetic Digital Anomaly Map using Satellite and Near-Surface Magnetic Data 208
Dan Lubin

Task 900-37-172: Parallel Numerical Kernels for Climate Models Based on the Object-Oriented Features of Fortran 90 and the Parallel Extensions of Co-Array Fortran 210
Robert W. Numrich

Task 900-37-172: Modeling Satellite Magnetic Data for the Earth and Mars 211
Kathy Whaler

Task 910-37-172: Aerosol Radiative Forcing of Climate 213
Maeng-ki Kim

Table of Contents (continued)

EDUCATIONAL PROGRAMS **215**

SHORT-TERM VISITORS **221**

APPENDICES **225**

References 227
Peer-Reviewed Publications 231
Other Publications 245
Conference Presentations and Publications 249
Grant Proposals and Status 273
Biographies 285
Faculty and Staff 317
Acronyms and Abbreviations 321

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EXECUTIVE SUMMARY

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Executive Summary

The Goddard Earth Sciences and Technology Center (GEST) is nearing the end of its fourth year of operation under a cooperative agreement between the NASA Goddard Space Flight Center (GSFC) and the University of Maryland, Baltimore County (UMBC). UMBC leads the GEST consortium, other members of which are Howard University (Washington, D.C.) and Hampton University (VA) as the other academic partners, and Caelum Research Corporation (MD) and Northrop Grumman Corporation (MD) from the private sector. This *Fourth Annual Report* is a compilation of GEST activities from 1 March 2003 to 29 February 2004. During this past year GEST was reorganized into eight research groups, each of which reflects the group members' research interests and their GSFC affiliation: Atmospheric Chemistry and Dynamics, Cloud Analysis, Cloud Modeling, Hydrological Sciences, Terrestrial Physics, and Information Sciences & Educational Technology; the membership of our faculty in the Global Modeling and Data Assimilation Office (GMAO) at GSFC was large enough to be subdivided into two groups: known as GMAO-A and GMAO-B. There are 114 reports by our research scientists, sorted by research group, including nine by our Goddard Visiting Fellows. There are 116 research personnel currently working under the rubric of GEST.

As an indication of the productivity of our staff, the bibliography of this report lists 175 peer-reviewed journal and book articles penned by GEST authors in the past year that have either been published or pending publication. There were two AGU monographs with our faculty as the lead editor; a third is due out in a month's time as of this writing. Further testimony to the prodigious scientific contributions of GEST's researchers were the 289 presentations at conferences, workshops, and other meetings that took place during the reporting period. Our researchers were involved as PIs or Co-Is in 106 grant proposals over this same period; they are currently working under 87 grants which have been either newly funded or carried over from previous years.

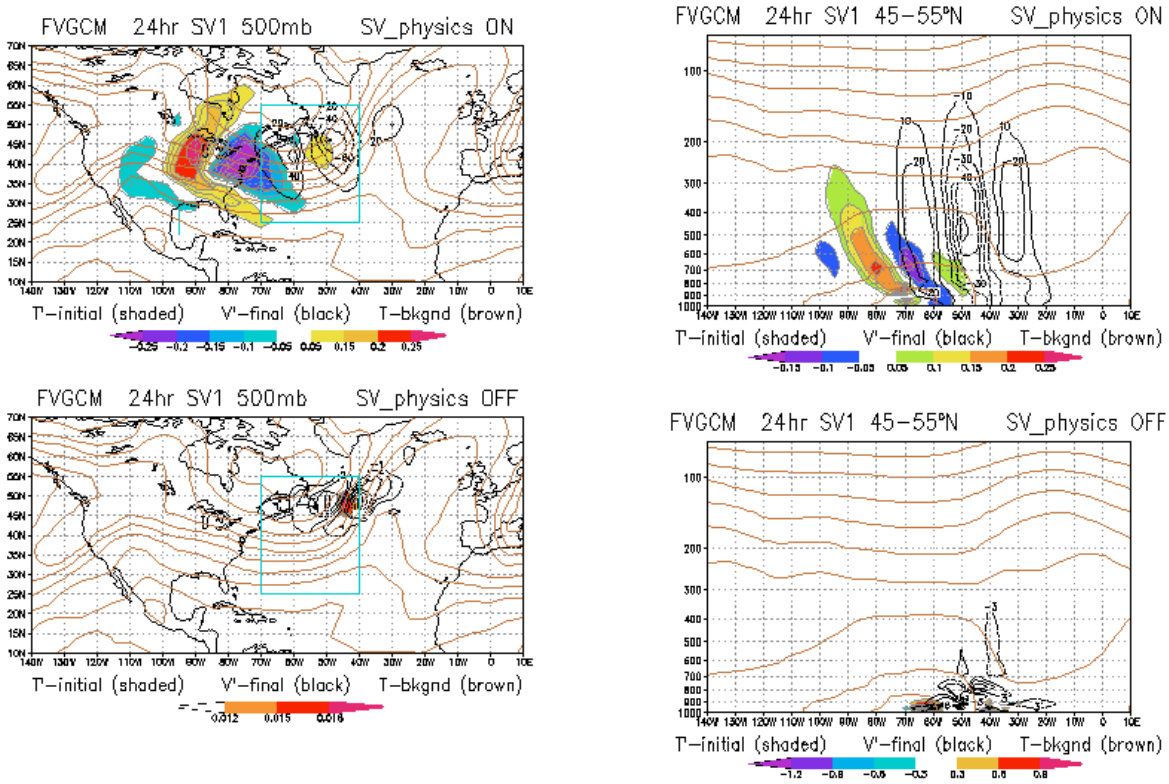
Despite cutbacks in financing for the summer enrichment student programs in the Earth and information sciences, the GEST Center successfully ran three summer educational programs at GSFC. Enrollment for these programs totaled 45 high school, undergraduate, and graduate students. As part of our summer program, a four-day seminar series was conducted, entitled "Measurement and Modeling of Aerosols, Clouds and Radiation", with eight distinguished speakers who are leaders in their respective fields of aerosol science. As part of our GEST outreach activities, these seminars were open for general attendance. To further support GEST efforts in the educational area, two GEST graduate fellowships were awarded to UMBC graduate students: one was in the Physics Department and the second in the Department of Computer Science and Electrical Engineering.

GEST also brings to GSFC and UMBC scientists from the international research community to collaborate with our local scientists through two important programs. The first is the Goddard Visiting Fellowship program, whereby senior scientists of international repute are brought to GSFC for up to a year's residency to conduct research, usually as a sabbatical from their home institution. A second category of new postdoctoral appointments under these fellowships assists promising young scientists who are just starting out in their careers. In addition, GEST facilitates the collaboration between scientists based at GSFC and those beyond this Center who are working for short periods at GSFC, at other research institutions, and at field sites around the world. Our staff was responsible for bringing 56 such visitors to GSFC for mutually beneficial studies in the Earth and Information Sciences.

Finally, the International Global Energy and Water Experiment (GEWEX) Project Office (IGPO) is firmly established as part of the GEST Center. A new director for the IGPO has been appointed to assist in the development and application of planetary Earth science and observations to the problems of climate and water resources worldwide. This inclusion of the IGPO in GEST's structure clearly reflects and embodies the goals and vision of the GEST Center.

Tom B. Low
Associate Director

Global Modeling and Assimilation Office
Research Group A



Horizontal (left) and vertical (right) structures of the leading singular vectors produced for a 24-hour forecast using the GMAO Finite-Volume GCM, with (top) and without (bottom) simplified diabatic physics.

Figures provided by Ronald Errico

Global Modeling and Assimilation Office Research Group A

The Global Modeling and Assimilation Office Research Group A (GMAO-A) worked on several problems related to atmospheric data assimilation and climate simulation. These included investigations regarding physical parameterization schemes, climate simulations, data assimilation within existing GMAO systems, assimilation of chemical species, and examining or developing advanced data assimilation techniques. Depending on the topic, approaches used by the investigators were complementary or standalone, but all support the goals of the GMAO.

Several investigators examined the effects of various physical parameterization schemes on either climate simulations or data analyses. Julio Bacmeister developed and validated new microphysical moist condensation schemes for use in the GMAO's finite-volume General Circulation Model (fvGCM). Specifically, he looked at how the specification of sea surface temperature (SST) affects the often-obtained misrepresentation of the intertropical convergence zone (ITCZ). Myong-In Lee compared the warm-season diurnal cycles in three models used at different research centers as part of an intercomparison project, looking at the observed cycle and with each other. The results of the models can have significant commonality, but there are differences in the output atmospheres in some important respects. Sarith Mahanama and Jiun-Dar Chern studied the effects of land surface models on both model simulation and assimilation. Maeng-Ki Kim examined forcing due to aerosols within the fvGCM, including interactions with microphysics and clouds, and documented the significant effects aerosols can have on simulations of regional climates. A means to "tag" water vapor so as to document its transport was developed and implemented by Jiun-Dar Chern. Yehui Chang determined correlations of the El Niño/Southern Oscillation (ENSO) and Madden-Julian Oscillation (MJO) with precipitation over parts of the United States simulated and observed data.

Shuhua Li evaluated and improved GMAO's data assimilation systems by examining the effects of gravity wave drag parameterization on stratospheric analysis. Hiroo Hayashi investigated the assimilation of tropospheric ozone, in both "online" and "offline" systems, showing the usefulness of including an interactive chemistry model. He also implemented a scheme developed by David Lary to correct erroneous ozone loss within the assimilation system.

David Lary has also been working on new, advanced techniques to assimilate chemical species, including the use of neural networks to estimate species correlations. Ronald Errico worked on dynamical aspects of the fvGCM data assimilation system, which included developing an fvGCM adjoint model to efficiently estimate data-sensitive regions in the cycling of the assimilation system and subsequent forecasts. He has also been leading an exploration of the potential of Ensemble Kalman Filter systems for future implementation of an advanced atmospheric data assimilation system at the GMAO.

Ronald Errico

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Task 910-01-008: **Chemical Data Assimilation**

GEST Investigator: David Lary

Collaborators: Michele Rienecker (PI, GSFC), Steven Pawson (GEST), P.K. Bhartia (GSFC), Mark Schoeberl (GSFC), Anne Douglass (GSFC), Richard Stolarski (GSFC), Mian Chen (GSFC), Ivanka Štajner (SAIC), Hiroo Hayashi (GEST), Doug Kinisson (NCAR), Joe Waters (JPL)

Abstract

Because Earth observation platforms require data validation, data assimilation is ideally suited to assist in this by providing objective metrics of agreement between observations and numerical models. This is particularly useful when the assimilation system has already been used to study data from existing validated platforms with which one can compare the metrics from the new, as yet unvalidated platforms. This is particularly relevant to the upcoming launch of the Earth Observing System (EOS) Aura platform. When modeling atmospheric chemistry, whether it is air quality, stratospheric ozone, or chemistry-climate interactions, coupled ordinary differential equations (ODEs) are solved. The solution of these ODEs is computationally expensive. A generic machine learning assisted ODE solver is desirable for stiff equations, with automatic error monitoring and continuous training. The ODE solver would also provide an associated error estimate of the solution, suitable for modeling atmospheric chemistry. The speed of such a solver should facilitate much higher-resolution and longer-duration simulations than have been possible to date.

Description of Research

Work performed under this task involves three areas of research in the Global Modeling and Assimilation Office (GMAO). The first area is multiconstituent chemical data assimilation, with particular emphasis in preparation for EOS Aura data acquisition. The second area is the use of neural networks to parameterize and accelerate various aspects of atmospheric chemical simulation. The third area is 3-D global chemical assimilation.

Accomplishments during the Reporting Period

An assimilation system has been prepared for satellite evaluation. Satellite instrument validation is obviously necessary, but sampling issues often make practical application problematic. This research aims to aid with EOS Aura constituent evaluation/validation by using the multivariate technique of data assimilation cast in Lagrangian coordinates. An advantage of assimilation is that it propagates information from data-rich regions to data-poor regions. Data assimilation also offers a mathematical framework to check and quantify the chemical consistency of multispecies observations with one another and with photochemical theory through the use of objective skill scores. That is, the assimilated analysis can examine both the consistency between different instruments observing the same constituent, and the photochemical self-consistency between multiconstituent observations and photochemical theory. The latter issue has not figured highly in previous satellite instrument evaluation. Chemical data assimilation can ingest observations from platforms such as the Aerosol Characterization Experiment (ACE), the Halogen Occultation Experiment (HALOE), and Polar Ozone and Aerosol Measurement (POAM) to prepare global stratospheric multiconstituent analyses. These analyses can then be sampled in the same way as the Aura instruments and compared with Aura observations using such tools as scatter diagrams, comparing probability distribution functions (quantile-quantile plots), and skill scores. The skill scores quantify various aspects of bias between observations and photochemical theory. Since the typical magnitude of these scores is known from previous assimilation studies they should be useful in highlighting any instrument biases that may be present in the Aura observations. Aura measurements could be processed similarly to the validating observations to produce global

stratospheric analyses, which are then intercompared with the same tools. Additionally, chemical data assimilation can add value to the Aura data by providing synoptic analyses for scientific studies in the same way that meteorological data are used to produce meteorological analyses that are then used in scientific studies. This is of particular interest to Mark Schoeberl (GSFC), Anne Douglass (GSFC), P.K. Bhartia (GSFC), Doug Kinisson (NCAR), and Joe Waters (JPL).

Addressing this task's second goal, neural networks are ideally suited to parameterize and accelerate various aspects of atmospheric chemical simulation. Neural networks have been used to describe the spatial and temporal dependence of tracer-tracer correlations. The neural network performs well even in regions where the correlations are less compact and normally a family of correlation curves would be required. For example, the CH_4-N_2O correlation can be well described using a neural network trained with the latitude, pressure, time of year, and CH_4 volume mixing ratio (VMR). A neural network using Quickprop learning and one hidden layer with eight nodes was able to reproduce the CH_4-N_2O correlation with a correlation coefficient between simulated and training values of 0.9995. Such an accurate representation of tracer-tracer correlations allows more use to be made of long-term datasets to constrain chemical models such as the dataset from the HALOE, which has continuously observed CH_4 (but not N_2O) from 1991 to the present. Work is now underway to use the neural networks to learn the behavior of ODEs and assist in their solution. This represents a strong collaboration between the GMAO and Anne Douglass (GSFC), Richard Stolarski (GSFC), and Mian Chen (GSFC) of Code 916, with whom biweekly meetings are held.

In the third task area, a 'cold-tracer' parameterization has been prepared for the GMAO ozone assimilation scheme to improve the ozone loss description in the ozone hole region. This has been transferred to Hiroo Hayashi (GEST) who has incorporated it in the GMAO ozone assimilation system.

Objectives for the Coming Year

The coming year will be dominated by two major new activities. The first will be to prepare multiconstituent chemical analyses for EOS Aura, due to be launched late in 2004. The second major activity will be to develop a generic neural network assisted ODE solver for stiff equations with automatic error monitoring and continuous training. This will be for use by Code 916 in the chemical transport simulations.

Task 910-05-082: **Reanalysis for Stratospheric Tracer Studies**

GEST Investigator: Shuhua Li

Collaborators: Steven Pawson (PI, GEST), Arlindo da Silva (GSFC), Shian-Jiann Lin (GSFC)

Abstract

Work performed under this task involves assessment of the reanalysis products, available for the period 1991-1995, using NASA's Goddard Earth Observing System (GEOS)-4 data assimilation system. The reanalysis products have been examined and compared with earlier work from GEOS-1 and assimilation products from other centers (*e.g.,* United Kingdom Meteorological Office (UKMO) and National Centers for Environmental Prediction (NCEP)). In addition, a sensitivity study was carried out in detail, with concentration on the impacts of gravity wave drag (GWD). A number of experiments were performed to investigate the impacts of GWD forcing on analysis of observed data and forecast fields. There is strong temperature sensitivity near the stratopause to inclusion of nonzero phase-speed gravity waves, especially in high hemispheric latitudes in winter.

Description of Research

This work involves reanalysis of meteorological fields and trace species in the middle atmosphere, over the period 1991 to 1995. Part of the project is to investigate the sensitivity of middle atmospheric

analysis to the formulation of the general circulation model (GCM). A major uncertainty in middle atmospheric modeling is the representation of subgrid scale GWD. Based on the GEOS-4 data assimilation system, the main objective of this project is to produce a validated, well-documented, four-year (1991-1995) dataset for use by the atmospheric science community.

Accomplishments during the Reporting Period

One of the major accomplishments during this period was achieved in a series of assimilation and forecast experiments by modifying parameters within the GWD scheme. This parameterization scheme allows for multiple wave forcing induced by convection or shear instabilities, as well as stationary waves due to orography. The results indicate that the effects of gravity wave forcing are predominantly significant in the winter hemisphere high latitudes in the mid-upper stratosphere. Inclusion of non-zero phase-speed gravity waves is very important for model forecast and analysis, especially in the middle atmosphere. As a statistical quantity, analysis (observed) minus forecast (O-F) tendency of geopotential height indicates that traveling gravity waves make a significant contribution to improving the analysis, while stationary waves have little impact in the middle atmosphere.

Another accomplishment was assessment of the reanalysis products. Some general features, such as temperature and zonal wind in the stratosphere, the residual mean circulation, etc., were investigated. The mass fluxes across the tropopause region were calculated and compared with earlier work for GEOS-1 and UKMO assimilations. The values of these fluxes are comparable, but the estimates from GEOS-4 appear to be smaller. This indicates less across-tropopause exchange in GEOS-4, which may be good for ozone budget and transport study, as in many modeling studies the across-tropopause exchange is overestimated.

Objectives for the Coming Year

Research activities will incorporate a volcanic aerosol scheme into the data assimilation system, and attempt to quantify the effects of Mt. Pinatubo eruptions on the analysis and model forecast. As of this writing, this project was to be completed in the first quarter of 2004.

Task 910-08-099: **Improvement of the Physical Parameterizations in the Finite-Volume General Circulation Model**

GEST Investigator: Jiun-Dar Chern

Collaborators: Shiann-Jiann Lin (PI, GSFC), Michael G. Bosilovich (GSFC), Jon Radakovich (SAIC)

Abstract

In recent years, our group has collaborated with the National Center for Atmospheric Research (NCAR) to develop the finite-volume General Circulation Model (fvGCM) for data assimilation, numerical weather prediction, atmospheric chemistry transport, and climate study. The fvGCM has employed a unique finite-volume dynamic core developed at GSFC [Lin and Rood 1996, 1997], and adopted the physics package from the NCAR Community Climate Model (CCM3), which represents a well-balanced set of processes with a long history of development and documentation [Kiehl *et al.* 1998]. The fvGCM has been successfully integrated into the Goddard Earth Observing System (GEOS) version 4 (GEOS-4) data assimilation system that became operational in 2003. During the reporting period the model's physical parameterizations and diagnostics were modified to improve the GEOS-4 analysis products and to meet the Global Modeling and Assimilation Office (GMAO)'s mission requirements. In addition, water vapor tracer (WVT) diagnostics have been developed, based on the physical parameterizations of the fvGCM to study the impacts of climate change on the global atmospheric water cycle.

Description of Research

The fvGCM is a NASA core model for data assimilation, numerical weather prediction, atmospheric chemistry transport, and climate study. Research objectives for this task are to maintain a state-of-the-art modeling system by improving the physical parameterizations; to improve the analysis products from GEOS-4 to meet the mission requirements of the Earth Observing System (EOS) science teams; to investigate the forecast capability of the fvGCM and GEOS-4 system; to modify the model for supporting data assimilation of new space-based observations; and to study the impact of these data on the system's forecasting skills and quality of analyses.

Accomplishments during the Reporting Period

Considerable effort has been devoted to improving the GEOS-4 surface skin temperature product to meet the requirements of Clouds and the Earth's Radiant Energy System (CERES) instrument teams. The recently developed state-of-the-art Community Land Model (CLM) version 2.0 [Bonan *et al.* 2002; Zeng *et al.* 2002], has been successfully integrated into the GEOS-4 system. The CLM2 was developed collaboratively by an open interagency/university group of scientists. It provides a comprehensive representation of several processes dealing with biogeophysics, biogeochemistry, ecosystem dynamics, and river routing. A considerable amount of time has been devoted to improving the biogeophysical processes in the CLM2 to reduce the model biases. Both the data assimilation of TIROS Operational Vertical Sounder (TOVS) surface skin temperature at a one-hour observing window and the new land model have led to significant improvements of surface skin temperature analysis and acceptance of the GEOS-4 product by the CERES instrument teams.

To advance our understanding of the global atmospheric water cycle and how it may change due to climate variability, the team has developed the WVT diagnostics based on the fvGCM physical schemes. In the WVT approach atmospheric water is "tagged" at its surface source as a constituent tracer and followed through atmospheric processes until it precipitates from the atmosphere. This technique permits quantitative study of the local and remote sources of precipitation at any point or area within the model's simulation. The most detailed diagnostic could be attained by using one WVT for each model grid point. Since each WVT is treated as a three-dimensional prognostic variable in the model, the number of WVTs in one model simulation is limited due to the availability of computing resources. In our study, the global water sources are divided into 4° x 5° boxes from 60° S to 70° N. To differentiate the contributions from land and ocean near the coastal region, two WVTs are used in each 4° x 5° box based on the model's land-sea mask. The total number of WVTs, therefore, is about 2500. Eleven simulations have been performed, each with more than 200 tracers, at 2° x 2.5^o resolution for the period 1948-1997.

The GEST investigator has successfully implanted the NCAR Whole Atmosphere Community Atmospheric Model (WACAM) gravity wave drag scheme and GSFC longwave radiation parameterization into standalone gridded components based on the Earth System Modeling Framework (ESMF). The gravity wave drag scheme includes parameterizations for orographic (stationary) gravity waves following McFarlane [1987], and for a spectrum of traveling gravity waves. The longwave radiative transfer scheme [Chou *et al.* 2003] includes absorption due to major gaseous absorption (*e.g.,* water vapor, CO_2, O_3) and most of the minor trace gases (*e.g.,* N_2O, CH_4, CFCs), and clouds and aerosols. The thermal infrared spectrum is divided into nine bands and one subband. To achieve a high degree of accuracy and speed, various approaches for computing the transmission function are applied to different spectral bands and gases. Both the gravity wave drag and longwave radiation gridded components have been tested offline. These two components will become the building blocks of the GMAO's next general circulation model.

Objectives for the Coming Year

In the coming year the GEST investigator will develop a multiscale modeling framework based on the fvGCM and the Goddard Cumulus Ensemble model (GCE). Other work will assess the performance and explore the capabilities of this system. Superparameterization for numerical

weather forecasting will be applied, and its impact on forecast skills will be studied. The superparameterization can also provide global simulations of the statistics of clouds that can be compared with new and emerging satellite platforms. Study will be performed on the detailed mean atmospheric water cycle (*i.e.,* surface evaporation source, WVT moisture transport, and WVT precipitation) for major cities and river basins in the world. The temporal and spatial climate variability of the regional and local water budgets will be evaluated using the principle analysis of the WVT diagnostics. In addition, the global map of local precipitation recycling based on grid box 4° x 5° will be examined.

Task 910-14-123: **The Impact of ENSO on Extreme Winter Weather of the Continental United States**

GEST Investigator: Yehui Chang

Collaborators: Siegfried Schubert (PI, GSFC), Max Suarez (GSFC)

Abstract

Research has led to better understanding of how the El Niño/Southern Oscillation (ENSO) and the Madden-Julian Oscillation (MJO) affect climate variability in the western U.S., including the occurrence of extreme weather (precipitation) events. Most current atmospheric general circulation models do poorly in simulating the MJO; as a result, their potential for forecasting variability associated with the MJO is limited. This study has forced the NASA Seasonal-to-Interannual Prediction Project (NSIPP)-1 atmospheric general circulation model (AGCM) with idealized MJO-like heating to examine the link between the MJO and extreme precipitation events over the western U.S. Results from the simulations are compared with observations that are composited according to the different phases of the ENSO and the MJO.

Description of Research

Relationships between the ENSO, MJO, and weather evolve on three different time scales consisting of the seasonal mean; low frequency, subseasonal transients (*i.e.,* time scales of approximately 10-90 days); and weather or high-frequency transients (*i.e.,* time scales of approximately 2-10 days). The understanding of how ENSO affects weather is central to understanding and predicting ENSO's impact on the U.S. climate. Robustness of the ENSO/weather connection clearly depends on a number of different processes that include the large-scale seasonal mean atmospheric response to tropical Pacific sea surface temperature (SST) anomalies and potential attendant changes in various subseasonal, low-frequency variations, such as the Pacific-North American (PNA) pattern and blocking. These linkages are complicated by potential nonlinearities that result in interactions between the various time and space scales under study.

Accomplishments during the Reporting Period

The GEST investigator contributed to all aspects of the project described here. The NSIPP-1 AGCM was integrated at 2° x 2.5° resolution. A 100-year control run was made with climate SST boundary conditions. Two 10-year runs were made with the climate SST, and forced with idealized MJO-like heating. The second run had the heating extended further to the east to mimic the eastward extension of MJO variability during El Niño events. The validation data sets for the above analyses include the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) global reanalyses, National Oceanic and Atmospheric Administration (NOAA) daily precipitation observations [Higgins *et al.* 1996] over the U.S. for the period 1949-2003, and outgoing longwave radiation (OLR) for the period 1974-2003 to help evaluate the model's ENSO and MJO response.

The most extreme precipitation events over Southern California tend to occur during El Niño winters. This result is quantified in terms of probability distribution functions (PDFs) of daily

precipitation maxima. The PDFs clearly distinguish El Niño winters from neutral and La Niña winters. The difference in the PDFs of daily precipitation maxima between La Niña and neutral winters is not significant. In addition to the link to El Niño, there is also a strong relationship between the extreme precipitation events over Southern California and tropical Pacific convection on intraseasonal timescales that appears to be linked to the MJO. The NSIPP-1 AGCM with idealized MJO-like heating reproduces the basic structures of the precipitation over Southern California and its phase relationship with the MJO, particularly for the case when the MJO heating extends further eastward across the dateline as is often observed during El Niño events.

Objectives for the Coming Year

The coming year will be dominated by new activities for the GEST investigator. The goal of the proposed work is to better understand how ENSO impacts the genesis, evolution, and intensity of the major winter storm systems, and how that translates into changes in the probability distribution of precipitation (particularly extreme events) over the U.S. Related goals are to evaluate the ability of the NSIPP model to simulate realistic precipitation extremes and to determine to what extent the simulations are improved by increasing the horizontal resolution.

Task 910-19-135: **Studies of Tropospheric Ozone in the GMAO Satellite Ozone Assimilation System**

GEST Investigator: Hiroo Hayashi

Collaborators: Ivanka Štajner (PI, SAIC), Steven Pawson (GEST)

Abstract

The satellite ozone assimilation systems developed at NASA's Global Modeling and Assimilation Office (GMAO) are being improved. Comparisons of tropical tropospheric ozone fields from experiments using the ozone assimilation systems with independent ozonesonde observations have revealed a beneficial impact of the online ozone assimilation system (which is included in the meteorological data assimilation system), and parameterized tropospheric chemistry. This has led to further improvements of the online ozone assimilation system.

Description of Research

Tropospheric ozone is environmentally important because it acts as a strong oxidant to control the concentrations of many reduced gases, such as methane and carbon monoxide, among others. Its radiative forcing plays a significant role in the greenhouse effect, and direct contact with ozone is harmful to human health. The main goal of this research is to better estimate the tropospheric ozone distribution by assimilating satellite ozone measurements. Many experiments using the assimilation systems have been performed and compared with independent observations to improve the system. These studies will also lead to better understanding of the mechanisms that determine the distribution of ozone in the real atmosphere.

Accomplishments during the Reporting Period

The ozone assimilation group in the GMAO now has two satellite ozone assimilation systems. One is the "offline" system, which is independent of the Goddard Earth Observing System (GEOS) meteorological assimilation system, except for using its wind and temperature output every six hours to drive ozone determination in the offline transport model. The other "online" system is incorporated into the meteorological assimilation system. In the online system, ozone is advected by the general circulation model (GCM) winds performed at the model time step of 30 minutes, and subject to the GCM parameterized processes.

Two experiments for 1998, using both offline and online ozone assimilation systems, have been performed. Ozone observations from the Solar Backscatter Ultraviolet Radiometer/2 (SBUV/2) were assimilated in the experiments. Parameterized ozone chemistry data for the troposphere provided from a Harvard University

group were examined. These results have been evaluated by comparisons with independent ozonesonde observations in the tropical troposphere from the Southern Hemispheric Additional Ozonesondes (SHADOZ) network.

A beneficial impact of the Harvard parameterized chemistry has been found. The ozone profiles were substantially improved in the lower levels in the troposphere, compared to experiments without the Harvard tropospheric ozone chemistry. A preliminary result using the online ozone assimilation system has shown much better tropospheric ozone profiles. Especially in the upper troposphere, assimilated ozone profiles were closer to the observed profiles. This improvement was thought to be mainly due to parameterized subgrid-scale convection and advection by winds produced at every time step in the online system GCM. Also, tropospheric column ozone was improved at all SHADOZ stations in the tropics.

As the experiments revealed clear benefits in using the online ozone assimilation system for studies of tropospheric ozone, most efforts in the reporting year were devoted to developing and improving the online system. A recent version of the ozone online system includes another parameterization of heterogeneous chemistry related to significant ozone depletion in the polar lower stratosphere (performed in collaboration with David Lary (GEST)), and can considerably reduce computing time compared to the previous versions. The latest version was used to provide real-time ozone forecasts for the pre-Aura Validation Experiment mission in January 2004. Also, an experiment to examine a different tropospheric ozone chemistry model (from a NASA Langley Research Center group) was completed using a version of the developing online system. This was a funded research project.

Objectives for the Coming Year

The online ozone assimilation system will be further improved and applied to scientific studies. One such application will be to examine the distribution of tropical tropospheric ozone over the Atlantic. It is known that the mid-tropospheric ozone maximum appears in the southern hemisphere in January to February, while seasonal agricultural burning, which is thought to be a major source of tropospheric ozone, occurs in the northern hemisphere. The ozone assimilation system being developed under this task would likely be useful in investigating the casual mechanism(s) of these interesting ozone distributions.

Task 910-31-155: **Goddard Earth Observing System Data Assimilation System**

GEST Investigator: Ronald M. Errico

Collaborators: Ronald Gelaro (PI, GSFC), Nathan Winslow (DSTI), Ricardo Todling (SAIC), Martin Ehrendorfer (UIBK), Kevin Raeder (NCAR), Rolf Langland (NRL), Thomas Rosmond (NRL), Carolyn Reynolds (NRL), Edward Barker (NRL)

Abstract

The GEST investigator has been working on a number of facets of data assimilation problems encountered at the Global Modeling and Assimilation Office (GMAO). These include developing adjoint model techniques and software to identify likely locations of data analysis errors, developing spectral and normal-mode analysis techniques and software for application on the GMAO general circulation model (GCM) grid, and developing adjoint-based analysis tools to rank the importance of observation types. The basis and progress of ensemble Kalman filter (EnKF) data assimilation has been examined as a possible foundation for a future GMAO data assimilation system (DAS), and the fundamental limits of atmospheric predictability have been estimated by using ensemble forecasts. The investigator is the chief organizer of the May 2004 *Sixth International Workshop on Adjoint Model Applications in Dynamic Meteorology*.

Description of Research

Many research and development activities require estimates of sensitivities of measures of output data with respect to uncertainties of input data. Adjoint models are powerful tools to efficiently determine such sensitivity when the number of output measures is very small but the input data set is very large. The GMAO is interested in using such tools to assist in determining the sources of errors in data assimilation systems. Adjoint models also reveal fundamental relationships in the atmosphere that should be properly considered when developing future data assimilation systems. These and other tools, such as nonlinear, normal-mode initialization software, require development, testing, and application to the GMAO data assimilation/forecast system.

Accomplishments during the Reporting Period

The GEST investigator has continued to develop an adjoint version of the GMAO finite-volume GCM. In particular, this has included developing appropriate tangent linear and adjoint versions of simplified semi-implicit vertical diffusion and planetary boundary layer parameterization schemes. Work was also done to develop processing software to determine an assortment of statistics of the outputs from tangent linear, adjoint, and nonlinear models and their differences.

The GEST investigator has also led a group examination of the theoretical basis and practical demonstrations of Monte Carlo techniques used for data assimilation. These techniques include both EnKF and ensemble square-root filters. Sixteen reports were carefully examined, with the conclusion that—while there is interest in these techniques—evidence for their success is still elusive and most related work suffers from damaging weaknesses. These weaknesses will be addressed in future work within GMAO and elsewhere.

Martin Ehrendorfer (University of Innsbruck; UIBK) has collaborated with the GEST investigator on developing a six-level, T42 quasigeostrophic spectral model. This model has much higher vertical and horizontal resolution than other such models. It is complex enough to exhibit significant nonmodal perturbation growth, but small enough to allow determination and manipulation of full-rank, flow-dependent covariance matrices to compute singular vectors and Kalman gain matrices. As such, it is an ideal intermediate model for examining questions whose answers will provide a foundation for developing future DAS.

The GEST investigator has collaborated with Carolyn Reynolds (Naval Research Laboratory; NRL) and Thomas Rosmond (NRL) in developing an analysis perturbation simulator suitable to study general atmospheric predictability and for ensemble forecasting. This technique attempts to draw realizations from a probability distribution function, describing analysis errors consistent with their best current statistical descriptions. Such errors are correlated vertically, horizontally, and between fields. Other collaborative work was undertaken with Edward Barker (NRL), using ensemble data assimilation techniques to estimate the background error statistics used by a typical DAS.

Objectives for the Coming Year

The GEST investigator will continue developing and applying adjoint-model tools for use with the GMAO DAS. This will begin with demonstration of their utility for localizing sources of errors within the DAS and for ranking the impacts of various subsets of observations. Also, packages for performing spectral and normal-mode transforms on the GMAO model grid will be developed. These will then be used to examine the imposition and maintenance of dynamical balances within the GMAO DAS and forecasting systems. With Martin Ehrendorfer (UIBK), examination of the basis for ensemble data assimilation techniques will be continued, using a range of models, including low-order illustrative models; medium-resolution, quasigeostrophic models; and the GMAO GCM. Work on general atmospheric predictability will continue with NRL collaborators (and, likely, from the National Centers for Environmental Prediction (NCEP), as well) to better characterize analysis, background, and forecast errors, and the relationships between them.

Task 971-00-002: **Parameterized Physics Development for Global Modeling and Assimilation Office Atmospheric Model**

GEST Investigator: Julio T. Bacmeister

Collaborators: Max J. Suarez (PI, GFSC), Franklin Robertson (MSFC), Atanas Trayanov (SAIC), Baode Chen (SAIC), Jiun-Dar Chern (GEST), Lawrence Takacs (SAIC), Frank Li (SAIC)

Abstract

Implementation of unified microphysical parameterizations for both convective and large-scale cloud condensate was completed in the NASA Seasonal-to-Interannual Prediction Project (NSIPP)'s atmospheric general circulation model (AGCM). The aim of this work is to improve the NSIPP AGCM's simulation of atmospheric moist processes, including precipitation and boundary layer cloud formation. The improved microphysical parameterizations also facilitated analysis of the so-called "double intertropical convergence zone (ITCZ)" bias in the NSIPP AGCM. This bias is a persistent source of error in most current AGCM simulations of tropical precipitation. The double ITCZ bias is exacerbated in coupled climate models, and may lead to significant errors in coupled forecasts.

Description of Research

The Global Modeling and Assimilation Office (GMAO) was established in 2003 to take over many of the tasks performed by the Data Assimilation Office (DAO) and NSIPP. The DAO's principal mission was to investigate and implement techniques to assimilate a variety of satellite atmospheric data, and to identify potential scientific and societal uses for these data. NSIPP's principal mission was to develop a fully coupled atmosphere/land/ocean climate prediction system to study the impacts of satellite-based ocean and land-surface observations on climate predictability. An important initial milestone for the GMAO is to develop a single atmospheric model capable of supporting all of these missions. Improved parameterization of atmospheric moist processes will be critical to the success of this modeling effort.

Accomplishments during the Reporting Period

The principal accomplishment of this project during this year was to successfully develop an initial version of the unified GMAO AGCM. This AGCM was constructed from components derived from the NSIPP and DAO AGCMs. The dynamical core of the model is the finite-volume core developed for the DAO by S. J. Lin. The model's moist physics are based on the single-phase prognostic cloud scheme developed for NSIPP by the GEST investigator. An important feature of the GMAO AGCM is its overall architecture, which relies on the Earth System Modeling Framework (ESMF) for component-to-component coupling. The decision to use ESMF meant paying a substantial initial price in terms of developing additional software. However, now that the ESMF architecture is in place, subsequent model development, including parameterization "swapping", should be easier than it had been previously. Building other applications using the AGCM or its components—for example, a single-column model for physics development—is now straightforward. As of February 2004 the GMAO AGCM had been run for short (several-day) integrations in "Aquaplanet" mode. With the exception of the land surface model and an extension to the planetary boundary layer (PBL) parameterization for estimating entrainment, the initial version of the model is fully implemented. The missing physics should have been addressed by the time of publication of this report.

In addition to the GMAO model development described above, work continued on understanding the physical causes of the so-called "double ITCZ bias" in climate models. The double ITCZ bias refers to a tendency for AGCMs to form two narrow, parallel bands (the ITCZs) of intense rain that extend from 10° S to 10° N of the Equator

across much of the Pacific Ocean. The double ITCZ bias is present to varying degrees in almost all current AGCMs. Unfortunately, in coupled simulations double ITCZs tend to be self-reinforcing because of the strong surface wind stress divergence that is induced along the Equator by the paired convergence zones on either side. A series of intensive, short (two-year), forced sea-surface-temperature (SST) simulations that began last year to isolate mechanisms responsible for the formation and/or suppression of the double ITCZ was completed. The conclusion of this study is that low-altitude cooling from reevaporation reduces boundary layer/convection coupling, which in turn makes formation of ITCZs more difficult. For reasons which are not yet clear but which may have to do with underlying SSTs, SST gradients, and water vapor transport, the southern ITCZ is suppressed more effectively than the northern one [Bacmeister *et al.* 2004].

Work on the prognostic cloud scheme for the NSIPP-2 AGCM was completed in early 2003. This model was used for several extended forced SST runs as part of GMAO's participation in the tropical cloud Climate Process Team (CPT). CPTs are a National Science Foundation (NSF)-led effort to foster nationwide collaborations aimed at resolving key problems in climate science. The GMAO, along with the National Center for Atmospheric Research (NCAR) and the Geophysical Fluid Dynamics Laboratory (GFDL), is participating in tropical cloud CPT activities. Analysis of multiyear simulations from the three centers has revealed a number of common deficiencies in their simulations of tropical cloudiness, including the "dim stratus, bright trades" bias, which is a tendency for the models to produce overly thin, shallow stratus decks in the eastern ocean basins, while producing excessively thick (bright) clouds in the trade cumulus zones further west.

Objectives for the Coming Year

The GEST investigator will finish implementing and tuning the complete physics package for the unified GMAO AGCM during the next year. Free-running multiyear simulations will be performed for diagnostic purposes and for inclusion in NSF's tropical cloud CPT modeling component. Incorporation of the GMAO AGCM into a new analysis/assimilation system will begin.

Task 971-00-002: **Physical Parameterization Studies for NASA's Seasonal-to-Interannual Prediction Project Atmospheric Model**

GEST Investigator: Myong-In Lee

Collaborators: Max Suarez (PI, GSFC), Siegfried Schubert (GSFC), Julio Bacmeister (GEST), Phil Pegion (SAIC), Isaac Held (GFDL), Arun Kumar (NCEP)

Abstract

In efforts to examine the moist physical parameterizations in NASA's Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric model, warm-season diurnal-cycle simulation of the continental United States and Northern Mexico has been investigated with the collaboration of researchers at the National Centers for Environmental Prediction (NCEP) and the Geophysical Fluid Dynamics Laboratory (GFDL). A set of benchmark calculations was designed to compare simulated climates and climate sensitivities of current models, facilitating explanations of the intermodel differences caused by different physical parameterizations. Their applicability has been examined with the NSIPP atmospheric general circulation model (AGCM), especially for tropical subseasonal variability studies.

Description of Research

Large uncertainties still lie in moist physical parameterization schemes (*e.g.,* cumulus parameterizations) and their interactions with grid-scale dynamics in AGCMs. These consequently limit the current capabilities of dynamical predictions. Investigation of the influences of moist physical parameterizations and extraction of clues for improving AGCMs has been carried out in two related research projects. The first was to

study the warm-season diurnal-cycle simulation of the continental United States and Northern Mexico. Current AGCMs do poorly in simulating the diurnal cycle and consequently do poorly in simulating the mean warm-season climate over much of the United States and Mexico, due to the fact that the diurnal cycle is a fundamental component of that climate component in those regions. This project was conducted in collaboration with both NCEP and GFDL modeling groups. The second project addressed moist benchmark studies, in which highly idealized test experiments were conducted to facilitate benchmarking current climate models and moist physics parameterizations. Both projects were conducted separately, but complemented each other to extend our understanding the moist physical parameterizations examined.

Accomplishments during the Reporting Period

The key task in this first year's effort was to assess and analyze the diurnal cycle in three different AGCMs used at GFDL, NCEP, and NASA. To establish a baseline assessment of the models, basic seasonal climatologies were compared. In summer precipitation climatologies the models showed a remarkable similarity in their biases, with a generally wet bias over northwestern Canada and Alaska, and a dry bias over the central and southwestern United States. An unexpected result of the comparisons was the similarity found among the three models (especially the NCEP and GFDL models) for many of the biases. Each group carried out the initial set of ensemble experiments for the warm season (May-September) driven by climatological sea-surface temperature (SST) at the current production resolution. Nocturnal jets over specified regions were generally produced appropriately, within some limitations. The overall diurnal cycle was generally consistent with estimates obtained from reanalysis data [Higgins *et al*. 1997], although there are clear differences in the magnitude of the diurnal oscillation. In the rainfall diurnal cycle, the observations showed a nighttime maximum in the central and northern Great Plains, whereas the NASA model tended to rain primarily in the early afternoon hours over much of the continent. The GFDL model captured the observed nighttime maximum, although it was shifted westward over mountains. The models were consistent with the observations in showing that precipitation in the eastern United States falls primarily during the daytime, but somewhat earlier than observed values.

Another effort was the moist benchmark study, in which a set of simplified experiments were designed and the base-line test experiments completed with the NSIPP AGCM [Bacmeister *et al.* 2000]. These experiments were highly idealized, in the spirit of the dynamical core benchmarks proposed by Held and Suarez [1994], but extended to moist atmospheres. The full moist physical parameterizations in the model were retained but the ocean covered the lower boundary of the model. Different configurations led to different analyses, and different forcings allowed us to examine the roles of various parameters in the models. A simplified sensitivity experiment for the climate change produced by doubling CO_2 concentration was designed to evaluate how the various models or physical schemes differ in the climate sensitivity and feedbacks. The detail of the benchmark test was documented at http://janus.gsfc.nasa.gov/~milee/mbmt.

By conducting the baseline experiments with the NSIPP model, some important issues could be addressed. One of the major findings was the influence of an interactive ocean on tropical subseasonal variability. Composite analysis of propagating waves revealed that an increased variability of rainfall in intraseasonal timescale was coupled with upper-level planetary-scale divergent motions that propagated eastward. The SST led convection over time, which is consistent with the SST feedback process in explaining eastward propagation of the Madden-Julian Oscillation (MJO). Despite the highly idealized conditions, a set of benchmark calculations was applicable to the tropical MJO and other climate change studies, which would be useful for the future AGCM intercomparison or other parameterization sensitivity studies in a much simplified framework.

Objectives for the Coming Year

Examination of the moist convection scheme in the atmospheric model will be extended during the coming year, with particular emphasis on linkages with the grid-scale dynamics. One of the key areas to be addressed will be the nature of the link

between the diurnal cycle in precipitation and the low level jets. Influences of the horizontal resolution on the diurnal cycle of simulated precipitation will also be investigated. Other work will address the simplified benchmark test of current atmospheric models to provide guidance in developing physical parameterizations. Intermodel and interscheme differences will be investigated by applying the benchmark test to other models. Of special interest will be different sensitivities in tropical subseasonal variability and cloud-radiative feedback caused by the physical parameterizations.

Task 971-00-002: **Parameterized Physics Development for Global Modeling and Assimilation Office Atmospheric**

GEST Investigator: Sarith Mahanama

Collaborators: Randal Koster (PI, GSFC), Max Suarez (GSFC), Michele Rienecker (GSFC)

Abstract

A Land Surface Model (LSM) that resolves water and energy budgets at the land surface is a vital component in a coupled land-atmosphere modeling system. Continuous improvement to the land surface parameterization scheme and evaluation of an LSM's performance are required to improve the coupled models forecasting skill. The Catchment LSM is the land surface model used in the Global Modeling and Assimilation Office's (GMAO) coupled modeling system. The Catchment LSM was implemented in the Global Soil Wetness Project Phase 2 (GSWP-2), in which performance of a number of LSMs used in climate models were evaluated at the global scale. In another series of global off-line experiments, the impact of atmospheric general circulation model (GCM) forcing biases due to soil moisture memory computed by the Catchment LSM and the Mosaic LSM were investigated. The GMAO's Unified LSM is being developed by merging components of other NASA-developed LSMs with the Catchment LSM. The first version of the unified model was tested globally, using GSWP-2 forcings with improved stomatal conductance parameterization; an impact on transpiration at high latitudes was observed.

Description of Research

The GEST investigator is involved in both LSM development and evaluation efforts at the GMAO. Participation in projects whose objective is intercomparison of land surface parameterization schemes allows performance evaluation of the LSM, and to comparison of its performance with other LSMs; GSWP-2 is one such project. Because simulated soil moisture memory in the LSM could have important effects on GCM precipitation forecasts, soil moisture memory produced by LSMs is being investigated to understand the relevant processes and to improve the coupled modeling system's forecast skills.

Accomplishments during the Reporting Period

There are clear benefits to evaluation and comparison of LSM performance with other commonly used LSMs in climate modeling. The GSWP-2 experiment was designed to force LSMs at one-degree resolution, using provided three-hourly forcings from July 1982 to December 1995. GSWP-2 will also test the impact of various atmospheric forcing datasets (*e.g.,* National Centers for Environmental Prediction (NCEP) and European Centers for Medium-Range Weather Forecasts (ECMWF) reanalysis data; effects of hybridizing with observed data) on the performance of participating LSMs. Ten LSM groups (including the Catchment LSM) have already turned in model outputs of the first of eight sensitivity experiments.

In a series of global off-line experiments, the degree to which biases in an atmospheric GCM affect the simulation of soil moisture memory within two LSMs was investigated. The Catchment LSM and the Mosaic LSM were both forced globally offline with a 0.5-degree, 6-hourly, 15-yr (1979-93) dataset, constructed from ECMWF reanalysis data that were corrected with

observation-based precipitation and radiation data. The two simulations were then repeated after imposing GCM climate biases on the forcings. The forcings were scaled so that their mean seasonal cycles matched those simulated by the NASA Seasonal-to-Interannual Prediction Project (NSIPP)-1 atmospheric GCM over the same period. Four of these supplemental offline global simulations were carried out with each LSM to determine the impact on simulated soil moisture memory of biased precipitation, biased downward shortwave radiation, and biased downward longwave radiation, separately, and biases in all three forcings together. The impact on the moisture memory was found to be significant. The impact of GCM biases on land-atmosphere feedback through evaporation was also investigated. Due to the distinct differences in performance of LSMs in different climate regimes, high land-atmosphere interaction has been arisen due to the GCM biases in the eastern part of the North American continent. Assuming sensitivity of precipitation to the local evaporation anomalies only, this may generate overconfidence in the coupled modeling system, resulting in a high precipitation forecast. The potential for correcting these memory biases through manipulation of soil water holding capacity was explored. The same experiment was repeated using the Mosaic LSM.

In related work, the Catchment LSM was set up globally to couple to the finite-volume GCM (fvGCM) at four different GCM resolutions. Catchment LSM-specific parameters, soil hydraulic parameters, and climatology of leaf area index and greenness fraction were derived for each land element using the most current global datasets available.

Objectives for the Coming Year

Work during the coming year will complete the remaining sensitivity experiments for GSWP-2. The major focus will be on investigating the impact of NCEP and ECMWF reanalysis atmospheric forcings. Several breakdown analyses have been planned to determine the differences in the schemes. Also, one sensitivity experiment will focus on using native parameters (*i.e.,* those used by modelers in their climate simulations) instead of GSWP-2 land surface parameters. Work will continue on the impact of GCM climate biases due to soil moisture memory to help determine how the change in climate regime has influenced the soil moisture memory. Further testing will be carried out in parallel with development of the unified model.

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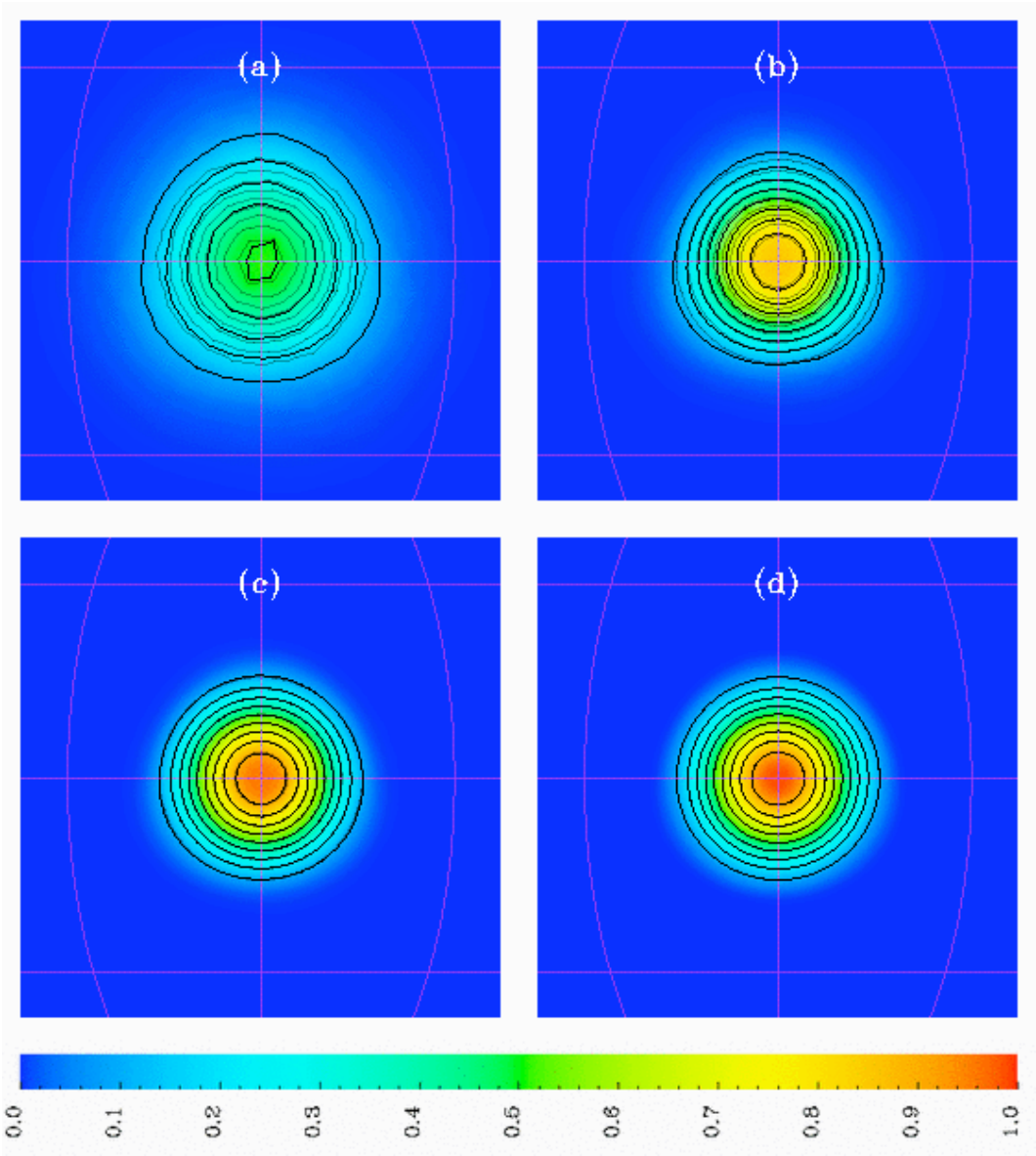
Global Modeling and Assimilation Office
Research Group B



Numerical solutions to a cosine bell advection over the poles by the SSI method after one revolution (12 days with a maximum speed 38.6 m/s) on icosahedral geodesic grids at the average resolutions of approximately (a) 500 km, (b) 250 km, (c) 125 km, and (d) 63 km. The numerical solutions, obtained with a fixed Courant number 0.5 relative to the average resolutions, are depicted by both colors and black contours. The analytic solutions, ranging from 0 to 1, are indicated by gray contours from 0.1 to 0.9 by 0.1. The numerical solutions converge to the analytic solutions very quickly with increasing resolution. Note that negative values, which have no physical meaning, do not exist in the numerical solutions; the errors are well localized; and the characteristic wavelengths of the cosine bell (mass distribution) are accurately maintained.

Figure provided by Kevin Yeh

Global Modeling and Assimilation Office Research Group B

The work performed by the members of the Global Modeling and Assimilation Office Research Group B (GMAO-B) addresses atmospheric modeling; climate research; and land, atmospheric, and oceanic data assimilation on a global scale.

Specifically, Kao-San Yeh, who is involved in next-generation atmospheric modeling, has been developing a new integration method that is to become the dynamical core of the NASA finite-volume general circulation model (fvGCM). Steven Pawson primarily focuses on tropospheric constituents, with emphasis on the carbon cycle. He is also involved in stratospheric research, using data analysis, modeling, assimilation, and validation. His exceptional scientific productivity is made manifest in the very high number of articles he co-authored during the past year. Augustin Vintzileos and Rosana Nieto Ferreira are involved in climate predictability studies. In particular, Vintzileos examines the seasonal-to-interannual time-scale, with emphasis on the El Niño/Southern Oscillation (ENSO) phenomenon, while Nieto Ferreira investigates longer, decadal-to-multidecadal time scales, examining precipitation over the Americas and Africa. Oreste Reale is involved primarily with synoptic and dynamic evaluations of the fvGCM, and with studies of the impact of various data types on prediction and analysis of extreme weather systems.

The remaining scientists in the group predominantly focus on different aspects of data assimilation. In particular, Peter Norris and Xin Lin are involved in rainfall and cloud assimilation studies. Norris has been developing a cloud parameter estimation scheme to assimilate satellite inferred clouds into the GMAO data assimilation system (DAS), while Lin has been developing a variational framework for assimilating satellite-derived surface rain rate and total precipitable water in the Goddard Earth Observing System (GEOS) DAS. Rolf Reichle, Sonia Seneviratne, and Chaojiao Sun are involved primarily in land surface studies and/or land surface data assimilation. Reichle has been developing a three-dimensional Ensemble Kalman Filter (EnKF) to reduce errors in soil-moisture estimates. Seneviratne, a visiting scientist from Switzerland, works on large-scale water balance estimates of changes in terrestrial water storage as part of an atmospheric GCM intercomparison project. Sun was originally involved in snow data assimilation in a land surface model. However, during the reporting period her main task changed and she now works primarily in ocean data assimilation in a global ocean circulation model, which will be her main task in future work. Lars Peter Riishojgaard leads the satellite data analysis group within the GMAO. The role of this group is to ensure that current and future satellite data from both research and operational satellites are assimilated as efficiently as possible. All these scientists are supported by the GMAO, with the exception of Oreste Reale and Kao-San Yeh, who are funded by the GSFC Laboratory for Atmospheres.

With such a diverse range of expertise and activities, it is difficult to define relationships between the results. However, it can be generally stated that all these efforts are in one way or another meant to provide some practical applications to a large community of users, namely the entire GMAO, the Laboratory for Atmospheres, and (more generally) the entire NASA community involved with Earth sciences. None of the scientists is working on individual, “pure” scientific projects, but all are part of a complex, multitasking, multidisciplinary team effort that can be evaluated only in its entirety and over several years of activity. In particular, the modeling effort is the one from which most researchers benefit over the long term, although it is the least spectacular when measured by timeliness of results and publications. Similarly, designing and developing complex data assimilation code is extremely beneficial for a broad user community, but such work generally does not produce many publications. Finally, work related to testing the impact of newly developed models and methodologies on, *e.g.,* forecast skill, is generally very time consuming and to some extent not always rewarding, since not all the code changes produce immediate and clearly favorable results, and improvements are obtained only after long trial-and-

error procedures. In spite of all these intrinsic limitations—typical of any scientific team effort—the group produced 17 publications that were either accepted or published in major peer-reviewed journals during the reporting period, plus a number of non-refereed publications and conference presentations. Finally, it should be mentioned that Steven Pawson has been awarded funding for two grant proposals, and that Rolf Reichle is now PI on one successful proposal effort and co-I on another two.

It is clear from the efforts reported here that each individual in this group is strongly motivated and clearly productive, and their plans for the coming year are challenging, appealing, and exciting.

Oreste Reale

Task 900-00-002: **Soil Moisture and Land Hydrology: Postdoctoral Visiting Appointment**

GEST Investigator: Sonia I. Seneviratne

Collaborators: Randal D. Koster (PI, GSFC), Paul A. Dirmeyer (COLA), Zhichang Guo (COLA), Martin Hirschi (ETH), Christoph Schär (ETH), Pedro Viterbo (ECMWF)

Abstract
Research conducted in the first five months of this one-year visit has included investigations on the derivation and use of large-scale water-balance estimates of changes in terrestrial water storage and the analysis of soil moisture memory from seven atmospheric general circulation models (AGCMs) participating to the Global Land-Atmosphere Coupling Experiment (GLACE).

Description of Research
Work under this task focuses on two main areas of research. The first deals with the derivation and use of large-scale estimates of changes in terrestrial water using a new approach based on water-balance considerations [Seneviratne *et al.* 2004]. The obtained data is of great potential for hydrological and climate research given the dearth of observations of terrestrial water storage and its components. The second area of research deals with the investigation and understanding of the mechanisms controlling soil moisture memory in AGCMs. These mechanisms constitute key aspects of land-atmosphere interactions and their understanding is of major implications for seasonal forecasting. The research presently conducted focuses on seven AGCMs participating in GLACE.

Accomplishments during the Reporting Period
In the first months of this visit, significant work has been performed in completing the final revisions to the study by Seneviratne *et al.* [2004]. In concert with a second study, which is in preparation, this work investigates the computation of changes in terrestrial water storage from water-balance computations and is performed in collaboration with Pedro Viterbo from the European Centre for Medium-Weather Forecasts (ECWMF), and Christoph Schär and Martin Hirschi from the Institute for Atmospheric and Climate Science at the Swiss Federal Institute of Technology (ETH).

The study by Seneviratne *et al.* [2004] demonstrates that changes in terrestrial water storage can be accurately estimated from water-balance computations for domains of the size 10^5-10^6 km^2 or larger, using atmospheric vapor data from the recent reanalysis product of the ECMWF (ERA-40) in combination with streamflow measurements. The study focuses on a 10-year period (1987-1996) and analyzes estimates computed with this methodology for the whole Mississippi River basin, its main subbasins, and a smaller domain (covering Illinois), where observations of total terrestrial water storage are available (*i.e.,* soil moisture, groundwater, and snow). The estimates are realistic for all subbasins, and the validation in Illinois is very satisfactory: The interannual variability and the mean climatology of the observed monthly changes in terrestrial water storage are well captured, with an excellent agreement in most years. These results are of critical importance for research in land hydrology since terrestrial water storage and its components (variables of key relevance for climate modeling and seasonal forecasting) are unknown in most parts of the world.

As a follow-up, a second study that encompasses the whole ERA-40 period (1958-2002) is now investigating estimates computed with the same approach for various river basins of the Northern mid-latitudes. This work has been performed in collaboration with Martin Hirschi, a doctoral student in the group of Professor Christoph Schär (ETH). The results of this study appear realistic for all river basins, and the obtained estimates generally compare well with soil moisture measurements wherever available, although a full validation—such as was performed for Illinois—is not possible, given the lack of concurrent measurements of groundwater and snow cover. An important finding is that the accuracy of the performed computations appears to depend both on domain size and regional characteristics.

An important project begun during this period deals with the analysis of soil moisture memory in present AGCMs. What is understood by "soil moisture memory" is the fact that the soil can "remember" a wet or dry anomaly long after the conditions responsible for the anomaly are "forgotten" by the atmosphere. This is a key aspect of land-atmosphere interactions and has significant implications for seasonal forecasting. This third study is conducted in collaboration with Randy Koster (GSFC) and Paul Dirmeyer and Zhichang Guo from the Center for Ocean-Land-Atmosphere Studies (COLA) in Calverton, MD. It is based on previous work performed by Randy Koster and Max Suarez (GSFC) and Sarith Mahanama (GEST).

The research presently being conducted on this topic focuses on seven AGCMs participating in the GLACE experiment, a recent project investigating the strength of land-atmosphere coupling in AGCMs. The present study investigates the soil moisture memory characteristics of the AGCM integrations, using an equation that relates the autocorrelation of soil moisture (*i.e.,* soil moisture memory) in climate models to four terms: seasonality in the statistics of the atmospheric forcing; the variation of evaporation with soil moisture; the variation of runoff with soil moisture; and correlation between the atmospheric forcing and antecedent soil moisture, which reflects both the memory of the external forcing and land-atmosphere feedbacks. The results show that the differences in regional soil moisture memory between the studied AGCMs can indeed be related to intermodel differences in these four controls.

Objectives for the Coming Year

Besides completing the studies described above, work will be devoted to two new projects. The first, conducted in collaboration with Rolf Reichle (GEST) and Randy Koster (GSFC) will set the basis for the possible use of the computed water-balance estimates of terrestrial water-storage variations in a data assimilation framework. Another project, conducted in collaboration with Matt Rodell (GSFC) and Pedro Viterbo (ECMWF), will conduct cross-comparisons between the water-balance estimates and first results from the Gravity Recovery and Climate Experiment (GRACE), which will provide remote sensing estimates of the same quantity.

Task 910-01-008: **Treatment of Atmospheric Trace Constituents in the Finite-Volume Data Assimilation System**

GEST Investigator: Steven Pawson

Collaborators: Michele Rienecker (PI, GSFC), Anne Douglass (GSFC), S. Randolph Kawa (GSFC), Richard S. Stolarski (GSFC), Mohan Gupta (GEST), Hiroo Hayashi (GEST), Shuhua Li (GEST), Andrew Tangborn (JCET), L. P. Chang (SAIC), J. Eric Nielsen (SAIC), Ivanka Štajner (SAIC), Wei-Wu Tan (SAIC), David Crisp (JPL), Gloria Manney (JPL), Daniel Jacob (Harvard University)

Abstract

Research under this task has led to improvements of our understanding of the impact of assimilation on transport, and to the development of analysis techniques to quantify the causes of such impacts. A complete validation of transport in several versions of the Global Modeling and Assimilation Office (GMAO)'s data assimilation system has been performed, using ozone and idealized tracers. Parameterized gravity wave drag (GWD) has been shown to have a large impact on assimilation and simulation. A strategy is being developed for a carbon species modeling and assimilation system that will utilize NASA's space-based data. Long model integrations have revealed substantial interannual variability in the circulation and composition of the middle atmosphere.

Description of Research

The GEST investigator is the lead scientist for trace constituent research in the GMAO. This work involves developing strategies for modeling

and assimilating trace gases in the atmosphere, studies of atmospheric dynamics and transport, and interactions with the land and ocean. Modeling work includes the implementation of chemically active gases in the finite-volume general circulation model (fvGCM); these range from simple implementations (*e.g.,* production and loss approximations) through complete representations of chemistry. An important science question concerns interactions between chemistry and climate, for which multiyear model simulations are performed and analyzed. Transport characteristics of the fvGCM and the finite-volume data assimilation system (fvDAS), the data assimilation system built around the fvGCM, are performed. The Reanalysis for Stratospheric Trace gas Studies (ReSTS) project is funded to produce analyses of the period 1991-1995, including aspects of sensitivity to various forcing mechanisms. Studies of the impacts of GWD on different ways of combining data and model are performed. Assimilation of various sources of ozone data is used to study their atmospheric distribution, with a focus on the lower stratosphere—partly in preparation for the upcoming launch of the EOS Aura platform, and for other space-based data, as well. This effort is expanding to include many different types of data, especially tropospheric trace gases. It involves developing an atmosphere-land-ocean assimilation system for carbon species, including inversion methods for source-sink determination.

Accomplishments during the Reporting Period

Stratospheric research has involved the continual analysis of the GEOS-4 (fvDAS) assimilation systems. The GEST investigator led the GMAO's effort to validate and improve products for middle-atmospheric transport applications, with a new version of GEOS-4, released in January 2004. This work was done in collaboration with L. P. Chang, Ivanka Štajner and Wei-Wu Tan (SAIC), and involved detailed study of different assumptions made in the fusion of model forecasts and observations. Impacts on meteorological fields, transport, and on the assimilation of ozone were studied, and the new version was shown to be an improvement on earlier versions of GEOS, especially for transport applications. This version of GEOS-4 is now frozen for the forthcoming EOS Aura launch, but will eventually be replaced by GEOS-5. The ReSTS will also use this model version, although some modifications have been made to better represent tropical wind variations.

The representation of GWD continues to be a major factor in middle-atmospheric models. Work to implement and improve a GWD scheme continues in collaboration with Shuhua Li (GEST) and Wei-Wu Tan (SAIC), and was used to examine impacts of GWD on assimilations in the Antarctic. Good progress is being made in forcing a quasi-biennial oscillation in the tropical lower stratosphere.

Substantial progress has been made in implementing middle-atmospheric chemistry into the fvGCM, an effort facilitated by close collaboration with Mohan Gupta (GEST), Anne Douglass and Rich Stolarski (GSFC), and Eric Nielsen (SAIC). The development phase of this research has been completed and future work will focus on implementation, making a fully coupled chemistry-climate version of the fvGCM for studies of ozone on the long-term change of the atmosphere.

Research on the ozone assimilation, being done collaboratively with Ivanka Štajner (SAIC), Hiroo Hayashi (GEST), and others, has resulted in substantial progress in the past year. Contributions have been made to efforts to implement the ozone assimilation on-line in the model, using improved representations of simple chemistry, to monitor data time series using assimilation, and to implement new types of data. One scientific driver for this work is the need to fully understand lower-stratospheric ozone, which is facilitated by including data from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), and will continue with data from NASA's EOS Aura platform. Substantial impacts on the system are found when MIPAS ozone data are assimilated. A system for carbon species is being developed along with the ozone assimilation. Carbon monoxide data from NASA's EOS platforms will be assimilated, in collaboration with Andrew Tangborn (JCET) and Daniel Jacob (Harvard). Work is progressing towards developing a framework for CO_2 assimilation, combining model development work (being done with Randy Kawa, GSFC) and data from the Orbiting Carbon Observatory (with Dave Crisp, JPL).

Objectives for the Coming Year

Model development will continue and studies of climate variability, including chemical variations and their radiative feedbacks, will be performed. Multi-decade integrations of the chemistry-climate system will likely lead to important advances. The model will also be used at high resolution to simulate small-scale features in atmospheric structure, to fuse the chemical modeling with observations from the EOS Aura platform. The launch of this platform in 2004 is expected to yield new data for ozone and other constituents, which will be assimilated. A major component of this work will be including the limb-sounder estimates of middle-atmospheric temperature in the meteorological analysis, to provide a better transport state for the constituent assimilation. Carbon species will require substantial attention, with emphasis on assimilating CO data from other instruments—including Measurement of Pollution in the Troposphere (MOPITT), the Advanced Infrared Sounder (AIRS), and the Tropospheric Emission Spectrometer (TES)—and development of strategies for incorporating CO_2 data.

Task 910-01-009: **Cloud Assimilation**

GEST Investigator: Peter M. Norris

Collaborators: Arthur Hou (PI, GSFC), Arlindo da Silva (GSFC)

Abstract

A cloud parameter estimation system has been developed to assimilate satellite cloud data into the NASA Global Modeling and Assimilation Office (GMAO)'s Goddard Earth Observing System (GEOS)-4 data assimilation system (DAS). Cloud fraction and optical depth data from the International Satellite Cloud Climatology Project (ISCCP) and cloud liquid water path retrievals from the Special Sensor Microwave/Imager (SSM/I) instrument are assimilated to improve the representation of model cloud properties and the resultant cloud radiative forcing, as independently validated against data from the Clouds and the Earth's Radiant Energy System (CERES) instrument. Last year's preliminary analysis of the system has been extended to show consistently good performance over a four-season period. The improvement in modeled cloud fraction has also been shown to continue in forecast mode, indicating that the improved parameter estimates can remove systematic errors in the model cloud parameterizations. Further positive impact was also found in modeled surface temperatures, particularly in the northern winter. Assimilation of Moderate Resolution Imaging Spectroradiometer (MODIS) Level-II cloud data began; initial results are promising.

Description of Research

Clouds play an essential role in moderating Earth's climate. This has prompted the recent development of a number of new cloud parameterizations for global climate models. However, the ability to test these new parameterizations against different sources of observed and retrieved cloud information with global or large-scale coverage is needed. Furthermore, at a time when many forms of ground-based and remotely sensed data are being assimilated into global models—such as the GMAO GEOS system—there are few mature efforts to directly assimilate cloud information into models. This task, then, addresses the use of retrieved cloud information to validate cloud properties within the GEOS model, to measure the capability of various new trial cloud parameterizations, and to assimilate cloud measurements directly into the data assimilation system.

Accomplishments during the Reporting Period

During this reporting period, a new cloud parameter estimation system, developed by the end of the last reporting period and described in last year's report, has been validated over the period December 1999-May 2001. Several aspects

of the system's performance have been thoroughly investigated. Task work resulted in development of the parameter estimation method and analysis of the need to assimilate multiple cloud properties (*e.g.,* cloud fraction, water path, and optical depth) to simultaneously improve both the cloud representation and the longwave and shortwave cloud forcing. The improved cloud fraction in assimilation mode is maintained in forecast mode, indicating that the cloud parameters estimated by the system correct systematic biases in the model cloud parameterizations. This is a significant result and holds promise for improving cloud parameterizations in climate models, which have long been known to be largely empirical, due to the mismatch in scale between clouds and the model resolution, and uncertainties in the microphysical properties of some clouds. The improvements in cloud properties and top-of-atmosphere longwave and shortwave cloud forcing are seen in all four seasons. This work has also illustrated the need for further improvement in optical depth assimilation, because longwave cloud forcing has shown more improvement than the shortwave cloud forcing. This leads to some deterioration in the net cloud forcing, since the base model has a reasonable net forcing, even though the component longwave and shortwave terms are each poor. Further modifications to the system will not be made until new GEOS-5 physical parameterizations are introduced—work that is planned for the coming year. New analysis of the surface energy balance was performed and an improvement in modeled surface temperature was demonstrated over northern latitudes in winter, due to the modified surface radiative forcing when clouds are assimilated.

The GEST investigator has received funding to assimilate MODIS cloud data into the GMAO GEOS-DAS and to study potential improvements to the model cloud parameterizations using this system. Code was written to read MODIS Level-II cloud granules and to project the data to the GEOS model resolution. This work was done with the help of Akinwale Olaleye, a NASA summer student. The system was developed to a point where MODIS cloud granules in a time window about each analysis period have been assimilated during a trial period of May 2001 with good results, comparable to the ISCCP system. Olaleye was subsequently employed on a part-time basis for the rest of the academic year to help with MODIS cloud assimilation. Further work is needed to fully understand the differences between MODIS and ISCCP retrievals, and to appropriately use the vast array of cloud information available within the MODIS cloud granule and cloud mask. This work is being carried out in consultation with Drs. Steven Platnick and Michael King of the MODIS science team.

Objectives for the Coming Year

Work will continue with the assimilation of MODIS cloud data, including the assimilation of new retrieved variables, such as cloud effective radius, as part of the Cloud-Radiation Modeling and Assimilation Interdisciplinary Science Investigation. ISCCP, SSM/I, and MODIS cloud data will be intercompared to assign error bounds on different retrieved cloud properties. The cloud assimilation system will be adapted to a new set of physical parameterizations as part of the GMAO's new GEOS-5 model, currently in development and testing. This model has significantly improved cloud and radiation parameterizations, including a combination prognostic-statistical cloud water parameterization, which should interface well with the cloud parameter estimation system. Dr. Hou's parameter estimation approaches for convective precipitation and this work on large-scale cloud parameterization will be studied in combination to produce a merged system. Finally, work on the cloud-aerosol indirect effect will begin later in the year, as part of Dr. da Silva's aerosol assimilation activities.

Task 910-01-010: **Satellite Data Group Leader**

GEST Investigator: Lars Peter Riishojgaard

Collaborator: Michele Rienecker (PI, GSFC)

Abstract
The main activity under this task is to lead the research and development efforts taking place in the satellite data group of the recently formed Global Modeling and Assimilation Office (GMAO). The new office is intended to serve as a central resource within GSFC (and NASA generally) for atmospheric modeling and assimilation of satellite data. The satellite data group currently consists of about 12 individuals, including both GEST faculty and private contractors; given the central role played by satellite data in GMAO strategic plans, the group is likely to expand over the next couple of years. The role of this group within the GMAO is to ensure that current and future satellite data—both from research and operational satellites—are assimilated as efficiently as possible and, when necessary, to initiate new experimental activities or develop new methodologies to ensure that this goal is met. The investigator is also the NASA deputy director of the NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA).

Description of Research
The work in the satellite data group falls into four main categories: supervising the routine assimilation of satellite data and troubleshooting; conducting data impact experiments to verify—and, where possible, improve—the impact of satellite data on GMAO systems; devising new methodologies appropriate for the acquisition and use of satellite data; and testing candidate new satellite data in GMAO systems.

Accomplishments during the Reporting Period
Progress has been made in all four focus areas addressed under this task. A comprehensive set of observing system experiments has been performed to assess the impact on GMAO systems of all major observation types. Experimental work on the Moderate Resolution Imaging Spectroradiometer (MODIS) wind products has led to operational implementation of these data in the GMAO system. Future work will focus on investigating the impact of these observations on the National Centers for Environmental Prediction (NCEP)'s operational systems. The MODIS wind data from the Earth Observing System (EOS) Aqua platform (launched in 2002) are also being studied, and experiments are being conducted that will help establish a solid baseline for the decision on how to integrate data from the first two MODIS instruments (on board EOS Terra and Aqua) into the assimilation cycle.

A proof-of-concept study in state-dependent data selection is underway. The rationale behind the study is that the analysis domain is highly heterogeneous with respect to its sensitivity to new observations: At any given time, there are large regions over which the atmosphere is largely quiescent, *i.e.*, no major developments are occurring or imminent, and the sensitivity to observational data is therefore expected to be modest. On the other hand, in areas with growing disturbances the sensitivity to observations is generally expected to be large, since a modest displacement of a certain feature in the initial conditions can have a profound impact on the forecast a few days later. An algorithm has been developed that stratifies the observations based on expected impact, and it has been applied to the selection of wind vectors provided by geostationary platforms. This work will be implemented in the selection of high-density soundings when the next-generation GMAO system becomes available.

The JCSDA continues to grow, and a substantial amount of time was spent on reviewing and managing the grants awarded by the JCSDA through its Announcement of Opportunity (AO). The investigator hosted a workshop on ocean-related studies at GSFC in June 2003. This workshop was sponsored by JCSDA through its first AO. In the fall of 2003 letters of intent and proposals for the second AO were reviewed.

Objectives for the Coming Year

A key goal for the satellite data group will be to help the GMAO transfer operations to an analysis that is closely related to what is used operationally at NCEP. Research versions of this new system will be implemented as they become available to demonstrate the impact of new data types and new methodologies on NCEP activities. This goal is closely aligned with the JCSDA mandate to accelerate the transition of both data and suitable methodologies from research to operations mode. Among the initial high-priority goals is to assess the impact of the MODIS winds on NCEP operations. Guidance for the development of future observing systems will continue.

Task 910-08-099: **Synoptic-Dynamic Evaluation and Improvement of the NASA Finite-Volume General Circulation Model**

GEST Investigator: Oreste Reale

Collaborator: Robert Atlas (PI, GSFC)

Abstract

This task focuses primarily on synoptic evaluation of various aspects of the NASA finite-volume General Circulation Model (fvGCM), originally developed in the Data Assimilation Office (now the Global Modeling and Assimilation Office; GMAO). In the final part of the year, this task was transferred to the Laboratory for Atmospheres at GSFC. The research investigates and improves the representation of individual high-impact weather systems in the fvGCM specifically, and in models in general, through a deeper understanding of the dynamics and physical mechanisms involved. During the past year, research was performed on two exceptional storms that affected northern and central Europe in 1999; on two tropical cyclones, which made landfall in the U.S.; on a case of exceptional floods that occurred in 2001 in the Mediterranean region; and on a case of a tropical cyclone in the southwestern Pacific.

Description of Research

The main goal of this task is to evaluate the potential of the fvGCM in simulating weather events at spatial and temporal scales near the limits imposed by model resolution, or events that generally represent a challenge from the modeling and data assimilation perspectives. These include "extreme weather events" like tropical cyclones (because of their relatively small size) or fast-developing mid-latitude cyclones. The research explores the impact of different data types (*e.g.,* satellite-derived wind and rainfall data, etc.) and different assimilation methodologies—in particular, synoptic situations in which additional data are critical. In the past, research on weather and climate were somewhat separated, because models designed for climate simulation were generally not capable of resolving weather events with a high level of accuracy. For the purposes of our work, we define "weather" as the sequence of instantaneous values taken by a generic atmospheric variable, and we define "climate" as the long-term time weather mean, with an averaging time chosen to be much larger than the time scales of the weather-induced fluctuations (*i.e.,* the so-called "synoptic-scale variability". Based on these operational definitions, reproducing synoptic-scale events within a climate-oriented model was found to be infeasible. In recent years, however, there has been growing attention in the climate community paid to the importance of so-called extreme events. The fvGCM system is one of the first models that have been designed to challenge the domains of climate and weather. Many other models, originally designed for climate studies, are now being tested to see how well they perform with extreme weather events.

Accomplishments during the Reporting Period

Tropical cyclones, floods and explosively developing cyclones (*i.e.,* cyclones which have a central pressure deepening rate greater than a certain latitude-normalized threshold), are examples of extreme events on which research has been performed under this task. In particular, research was done in collaboration with two other

scientists at GMAO to evaluate the impact of a precipitation assimilation technique previously developed by Dr. A. Hou (GSFC) on the dynamic and synoptic representation of tropical cyclones in the model GEOS-3. In particular, the methodology was tested on two hurricanes that affected the U.S. mainland, Bonnie (1998) and Floyd (1999). The synoptic and dynamic analysis performed in this task shows that Dr. Hou's technique produces a remarkable improvement in the way in which hurricanes are represented in a global model [Hou *et al.* 2004]. Another type of extreme event, an extreme flood in the Mediterranean region in October 2000, was investigated collaboratively with Prof. F. Siccardi, from the University of Genoa. This event was remarkable because it occurred without any significantly deep cyclone over the region. Analysis showed that most of the moisture was produced in the tropics and was advected towards the Mediterranean by the extratropical transition of an earlier tropical storm in the eastern Atlantic. A water vapor back-trajectory technique, developed by Dr. P. Dirmeyer at the Center for Ocean-Land-Atmosphere Studies (COLA), was used. This technique has shed some light on the importance of water vapor back-trajectories in investigating how moisture is being transported and properly represented in models. Research continued in collaboration with Dr. Riishojgaard (GEST) on two very intense storms that occurred in France in December 1999, each of which had winds with speeds near 150 mph. Many assimilation experiments were performed, focusing on the impact of two satellite products: wind vectors derived from the European Meteosat and NASA's QuikSCAT. When assimilating these wind data sets the radius of influence of observations and their weighting were perturbed. The results show that the analyses and forecast are very sensitive to the representation of two jets, one in the upper-level and one close to the surface. There is some controversy about the complexity of the new dynamical implications unveiled during these studies; therefore, research is still in progress.

Research continues on anomalous cases of small-scale convective cyclones that resemble tropical cyclones, but are detected in the midlatitudes.

Finally, new research began on investigating the impact of the Special Sensor Microwave Imager (SSM/I) and Advanced Infrared Sounder (AIRS) data on the representation of the finite-volume model of a particularly interesting case of a tropical cyclone in the southwestern Pacific [Beni 2003]. The cyclone is remarkable because of an anomalous trajectory: a tight loop that skirted the island of New Caledonia completely, without making landfall. This loop was missed by all operational weather forecasting systems. Several experiments are being analyzed to determine what information might provide critical forecast improvement. This work may unveil fundamental aspects of the dynamics of the tropical cyclones in the southwest Pacific, which are less studied than those in the northern hemisphere.

Objectives for the Coming Year

The main goal of this task will be to continue evaluating the potential of the fvGCM in simulating weather events at spatial and temporal scales near the limits imposed by model resolution. The research will also continue to explore the impact of different data types (*e.g.,* satellite-derived wind data, rainfall data, etc.) on synoptic models, which can represent challenges for the fvGCM. Collaboration with scientists within and outside NASA will continue, and research will be conducted to investigate any new, fundamental aspects of synoptic and dynamic meteorology that might arise during the evaluation of the fvGCM.

Task 910-14-124: **Rainfall and Cloud Assimilation**

GEST Investigator: Xin Lin

Collaborator: Arthur Hou (PI, GSFC)

Abstract
A variational framework for assimilating the Special Sensor Microwave Imager (SSM/I)-derived surface rain rate and total precipitable water (TPW) has been developed, and its impact on the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) has been examined over the Tropics. This research is being performed in an attempt to apply the same methodology to midlatitude weather systems, and to evaluate its impact on analyses and forecasts of midlatitude winter storms. Algorithms to assimilate cloud data will be developed.

Description of Research
Rainfall data retrieved from satellites can be used to directly constrain systematic errors in model physics. A procedure for assimilating six-hour average surface rainfall and TPW estimates derived from SSM/I has been developed; the global analysis produced by the GEOS DAS shows a significant improvement in the Tropics after assimilating the rainfall and TPW data [Hou *et al.* 2000; Hou *et al.* 2002].

The Global Precipitation Measurement mission (GPM) plans to have a multiple-satellite constellation to achieve three-hourly sampling at any given point on the globe, 90% of the time or better. To serve as a pilot study for GPM, plans call for assimilating Advanced Microwave Scanning Radiometer (AMSR) rainfall data from the Earth Observing System (EOS) Terra and Aqua platforms, and to examine their impacts on analyses and forecasts of weather systems in midlatitudes. At a later stage, when the new prognostic cloud scheme is implemented in the Global Modeling and Assimilation Office (GMAO) assimilation system, algorithms will be developed to assimilate cloud data from Moderate Resolution Imaging Spectroradiometer (MODIS) and CloudSat-based instruments to better constrain physical errors from model cloud microphysics.

Accomplishments during the Reporting Period
GEOS DAS3 has been modified so that varying large-scale forcings, which are more realistic for midlatitude baroclinic frontal systems than earlier approaches, can be used to drive the column model. Several sensitivity experiments have been performed to evaluate the impacts of different data assimilations. Pixel-size data from the Clouds and Earth's Radiant Energy System (CERES) instrument have been extensively analyzed and examined at six-hour intervals. When AMSR data are officially released, they will be assimilated into GEOS DAS3, along with data from SSM/I and the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (MI).

Objectives for the Coming Year
Objectives for the coming year include evaluating the capabilities of GEOS DAS3 after assimilating AMSR rainfall data, and developing algorithms to assimilate satellite cloud data. Preliminary methodologies to assimilate cloud data into cloud system models will commence.

Task 910-14-125: **Development of a Next-Generation Finite-Volume Dynamical Core on Geodesic Grids**

GEST Investigator: Kao-San Yeh

Collaborator: Robert Atlas (PI, GSFC)

Abstract
Work during the reporting period including developing the Streamline Subgrid Integration (SSI) method to model geophysical fluid dynamics on arbitrary grid systems, such as spherical geodesic grids. SSI-based second-order transport schemes have been successfully constructed with great accuracy and efficiency for icosahedral geodesic grids. Such schemes are particularly useful for global high-resolution applications.

Description of Research
The goal of this project is to develop a next-generation dynamical core with the finite-volume method on geodesic grids. This potential dynamical core is intended for future application in the NASA/National Center for Atmospheric Research (NCAR) finite-volume general circulation model (fvGCM) as a major component for global high-resolution modeling. While the quasi-uniform geodesic grids provide a good foundation for achieving significant efficiency for the enormous amount of computation required by global high-resolution, the main effort is to overcome the scientific difficulty of developing sufficiently accurate finite-volume algorithms for non-orthogonal grids.

Accomplishments during the Reporting Period
During the reporting period, the GEST investigator developed the Streamline Subgrid Integration (SSI) method for modeling geophysical fluid dynamics on arbitrary grid systems, such as icosahedral geodesic grids in spherical geometry. The SSI method has proved to be highly accurate with physically meaningful properties. Second-order transport schemes based on the SSI method have been successfully constructed with great accuracy and efficiency on icosahedral geodesic grids. They are particularly useful for global high-resolution applications on icosahedral geodesic grids, because their convergence rates have proved to be faster than other high-order schemes with different methodologies on traditional longitude-latitude grids. Icosahedral geodesic grids are known to be much more efficient and have higher capacity for parallel computing with modern high-end computers than traditional longitude-latitude grids.

Objectives for the Coming Year
Work in the coming year will include extending the SSI method from second-order accuracy to the third order, and constructing a shallow-water model with the SSI method on icosahedral geodesic grids in preparation for constructing 3-D atmospheric dynamical cores.

Task 971-00-002: **Interdecadal Variability of Precipitation in the Americas and Africa**

GEST Investigator: Rosana Nieto Ferreira

Collaborators: Max Suarez (PI, GSFC), Siegfried Schubert (GSFC)

Abstract
The decadal-to-multidecadal variability and predictability of precipitation in the Americas and Africa were studied using the NASA Seasonal-to-Interannual Prediction Project (NSIPP)-1 general circulation model (GCM). Several regions in the Americas and Africa have decadal-to-multidecadal precipitation variability that is tied to sea surface temperature (SST) variability. In this study, various patterns of SST variability are shown to play a role in the observed decadal-to-multidecadal variability of precipitation.

Description of Research

This project focuses on the decadal-to-multidecadal variability and predictability of climate in the Americas and Africa using results from the NSIPP-1 GCM. The National Centers for Environmental Prediction (NCEP) reanalysis and Global Historical Climatology Network (GHCN) precipitation datasets (1900-present) are used to validate model results.

The predictability of various precipitation indices is assessed using tier-2 ensembles of NSIPP-1 land-atmosphere model simulations. In these simulations sea-surface temperature (SST) is prescribed, and therefore the ocean model is not involved. This study is based on a 14-member ensemble of 70-year long simulations that use prescribed monthly mean Hadley Center SSTs. The degree to which the temporal variability of these indices is reproducible in the ensemble simulations indicates how important SSTs are in determining the observed precipitation variability and is a measure of the degree of predictability of the decadal-to-multidecadal variability of precipitation in these regions.

Accomplishments during the Reporting Period

The precipitation data from both the model and observations were filtered using a low-pass filter that retains slow variability of timescales longer than eight years. A significant correlation was found between observed and modeled precipitation indices in various regions of the Americas and Africa, such as northeast Brazil, subtropical South America, and parts of the Amazon region, as well as in the so-called North American Monsoon region and southern Great Plains of the U.S., and in the African Sahel and forested areas to its south. This indicates that the decadal-to-multidecadal variability in these areas is tied to the SST variability, and therefore has some degree of predictability.

To find out what SST patterns contribute to the precipitation variability in the aforementioned regions, an empirical orthogonal function (EOF) analysis of low pass filtered SST is performed. The results show an EOF that represents a slow warming trend of South Atlantic and Indian Ocean SSTs from the 1930s to the present. This mode explains 31% of the variance and is hereafter referred to simply as “trend mode.” The second EOF is the well-known “Pacific Decadal Mode” and explains 17% of the variance. The fifth EOF explains 7% of the variance; its pattern is a tripole of SSTs that spans the tropical and North Atlantic Ocean. This mode is hereafter referred to as “North Atlantic Mode.” Correlations between the low-pass filtered observed precipitation indices and the principle component (PC) time series of the aforementioned modes were calculated. The trend mode PC time series was found to have significant correlation with the precipitation indices in most of the regions studied. The Pacific Decadal mode PC time series has significant correlation with the precipitation indices in northeast Brazil, portions of the Amazon region and the North American Monsoon region. The North Atlantic mode has significant correlation with the precipitation indices in northeast Brazil, the Sahel, and the North American Monsoon and Great Plains regions.

Twenty-year-long NSIPP-1 GCM simulations were then performed using the climatological precipitation as SST forcing, modified to include the positive and negative SST anomalies of each of the modes above. This is done to study how each of the SST modes contributes to the decadal-to-multidecadal variability of the observed precipitation in the Americas and Africa. In good agreement with the results suggested by the correlations between the modes PCs and the observed precipitation index time series, the trend mode was found to have significant impact on precipitation in most of the regions studied. The Pacific Decadal mode has significant impact on precipitation in the North American Monsoon region, Southern Great Plains, northeast Brazil, and South Africa, and the North Atlantic mode has significant impact on precipitation in northeast Brazil.

Objectives for the Coming Year

Work during the coming year calls for using the aforementioned NSIPP-1 simulations to study the mechanisms through which the trend, Pacific Decadal, and North Atlantic modes affect the decadal to multi-decadal variability of precipitation in the Americas and Africa.

Task 971-00-002: **Land Data Assimilation in Support of NASA's Seasonal-to-Interannual Prediction Project**

GEST Investigator: Rolf H. Reichle

Collaborators: Michele Rienecker (PI, GSFC), Randal Koster (GSFC), Matt Rodell (GSFC), Max Suarez (GSFC), Dennis McLaughlin (MIT), Dara Entekhabi (MIT), Jeffrey Walker (University of Melbourne, Australia)

Abstract

The one-dimensional (1-D) Ensemble Kalman filter (EnKF) was earlier demonstrated to be suitable for deriving estimates of soil moisture from remote sensing observations for land initialization of seasonal climate forecasts. The newly developed three-dimensional version of the EnKF can make use of potential horizontal correlations in model, forcing, or observation errors and can further decrease soil moisture estimation errors. A comparison of available global soil moisture datasets showed that magnitudes of time-averaged soil moisture and soil moisture variability are markedly different in many locations. Absolute soil moisture values from satellite and model soil moisture are very different, and neither agrees better than the other with ground (*in situ)* data, implying that a "correct" soil moisture climatology cannot be identified with confidence from available global data. The discrepancies between the datasets point out the need for bias estimation and correction (or rescaling) before satellite soil moisture can be assimilated into land surface models (LSMs).

Description of Research

A central goal of the Global Modeling and Assimilation Office (GMAO) is to develop a land data assimilation system that makes optimal use of existing and planned remote sensing observations for improved predictions of seasonal-to-interannual climate variations. Seasonal climate forecasting must rely on the correct initialization of the slow components of the Earth system, namely the oceans and the land surface. At the land surface, soil moisture controls the partitioning of moisture and energy fluxes to the atmosphere and is a key variable in weather and climate prediction. The "memory" associated with soil moisture is likely the chief indicator of midlatitude forecast skill.

Accomplishments during the Reporting Period

The importance of horizontal error correlations in background (that is, model forecast) fields for large-scale soil moisture estimation was assessed by comparing the performance of one- and three-dimensional ensemble Kalman filters (EnKF) in a twin experiment [Reichle and Koster 2003]. Over a domain centered on the United States Great Plains, gauge-based precipitation data was used to force the "true" model solution and reanalysis data for the prior (or background) fields. The difference between the two precipitation datasets is thought to be representative of errors that might be encountered in a global land assimilation system. To ensure realistic conditions, the synthetic observations of surface soil moisture matched the spatiotemporal pattern and expected errors of retrievals from the Scanning Multichannel Microwave Radiometer (SMMR) on the Nimbus-7 satellite. Taking horizontal error correlations into account in the EnKF improved estimation accuracy. Soil moisture estimation errors in the EnKF were smallest for a correlation scale of 2° in model parameter and forcing errors, which coincides with the horizontal scale of difference fields between gauge-based and reanalysis precipitation. In our case, the 3-D EnKF required 1.6 times the computational effort of the 1-D EnKF, but this factor depends on the experiment setup.

Next, three independent surface soil moisture datasets for the period 1979-87 were compared: (1) global retrievals from the Scanning Multichannel Microwave Radiometer (SMMR); (2) global soil moisture derived from observed meteorological forcing using the NASA Catchment LSM; and (3) ground-based measurements in Eurasia and North America, from the Global Soil Moisture Data Bank [Reichle *et al.* 2004]. Time-averaged soil moisture fields from

the satellite and the model largely agreed in the global patterns of wet and dry regions. Moreover, the time series and anomaly time series of monthly mean satellite and model soil moisture values were well correlated in the transition regions between wet and dry climates where land initialization may be important for seasonal climate prediction. However, the magnitudes of time-averaged soil moisture and soil moisture variability were markedly different between the datasets in many locations. Absolute soil moisture values from the satellite and the model were very different, and neither agreed better than the other with ground data, implying that a correct soil moisture climatology cannot be identified with confidence from the available global data. The discrepancies between the datasets point to a need for bias estimation and correction or rescaling before satellite soil moisture can be assimilated into LSMs.

In addition to assimilation of satellite soil moisture data, forcing a LSM in offline mode with realistic global fields of precipitation, radiation, and near-surface meteorology produces realistic fields (within the context of the LSM) of soil moisture, temperature, and other land surface states. These fields were then used as initial conditions for precipitation and temperature forecasts with an atmospheric general circulation model (AGCM). Retrospective one-month forecasts were performed with the GMAO seasonal prediction system. The 75 separate forecasts provide an adequate statistical basis to quantify improvements in forecast skill associated with land initialization. Skill evaluation focused on the North American Great Plains, a region with both a reliable land initialization data and a known ability of soil moisture conditions to overwhelm atmospheric chaos in the evolution of the meteorological fields. The land initialization caused a small but statistically significant improvement in precipitation and air temperature forecasts in this region. The joint initialization of land and atmospheric variables was considered in a supplemental series of ensemble forecasts. Potential predictability from atmospheric initialization dominated over that from land initialization during the first two weeks, whereas land initialization contributed more to potential predictability during the final two weeks. Both land and atmospheric initialization independently contributed to the actual skill of the monthly forecast, with the greatest skill derived from the initialization of both.

Objectives for the Coming Year

The first objective for the coming year is to prepare for global assimilation of currently operational satellite data from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E). The retrospective and current soil moisture assimilation products will be tested in seasonal hindcasts and forecasts of midlatitude summer precipitation with the GMAO seasonal forecasting system. Also, the joint assimilation of soil moisture and snow data will be examined.

Task 971-00-002: **Ocean Data Assimilation in a Global Ocean Circulation Model**

Task 974-03-070: **Snow Data Assimilation in a Land Surface Model**

GEST Investigator: Chaojiao Sun

Collaborators: Michele Rienecker (PI, GSFC), Christian Keppenne (GSFC), Jeffrey Walker (University of Melbourne, Australia), Paul Houser (GSFC), James Foster (GSFC)

Abstract

Work under the first task focused on the observational impact on seasonal forecasting of different coupled models initialized with ocean states produced from different ocean data assimilation schemes, and the comparison of ocean assimilation diagnostics. The second task focused on developing an error model for satellite retrieval of snow water equivalent from passive microwave instruments. The reporting period

started with the continuation of the second numerically listed task and then transitioned to the first numerically listed task.

Description of Research

Research has shown that with longer assimilation windows, optimal interpolation (OI) assimilation schemes improve the analyses of subsurface ocean states and, as a consequence, improve coupled forecasts. The Ensemble Kalman filter (EnKF) has been shown to have better hindcast skills than OI. An error model has been developed for snow water-equivalent observations measured from satellites using passive microwave sensors. A framework has been developed for the assimilation of remotely sensed snow observation products into the NASA Seasonal-to-Interannual Prediction Project (NSIPP) land surface model (LSM).

Accomplishments during the Reporting Period

There were two major accomplishments during this reporting period. The first deals with ocean data assimilation research, the other related to snow data assimilation.

One of goals of the NOAA Climate Dynamics and Experimental Prediction (CDEP) Consortium for Ocean Data Assimilation for Seasonal-to-Interannual Prediction (ODASI) is to evaluate the impact of observational data on seasonal forecasts made using different coupled ocean-atmosphere models that utilize different ocean assimilation systems to produce initial ocean boundary conditions. Forecast skills are evaluated by the correlations of observed and analyzed sea surface temperature (SST) anomalies over the tropical Pacific. Work on ODASI efforts has been underway since June 2003, and includes leading the effort to compare the analyses from different ocean data assimilation systems (ODAs), including those from the Geophysical Fluid Dynamics Laboratory (GFDL), the Center For Ocean-Land-Atmosphere Studies (COLA), and NSIPP, who are partners in the ODASI consortium, along with the National Centers for Environmental Prediction (NCEP). Edwin Schneider (COLA) leads the forecast analysis activities.

Other work under this task has developed an error model for satellite retrieval of snow water equivalent from passive microwave instruments (*i.e.,* the Special Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave Imager (SSM/I)). This work has important implications for snow data assimilation, since this is the first time that errors have been quantified for passive microwave snow observations. It is also important for snow model developers, since it addresses contributions to observational errors, *i.e.,* it takes into account the masking effect of vegetation cover and passive microwave response to snow crystal sizes. A new time-evolving and vegetation-dependent algorithm was proposed, and the uncertainty related to the new algorithm was quantified. The results were validated using ground snow water-equivalent observations from the Canadian Climate Center. This work can be easily extended to Advanced Microwave Scanning Radiometer for the Earth Observing System (EOS) (AMSR-E) measurements.

Objectives for the Coming Year

Work in the coming year will develop diagnostic tools to evaluate different ocean data assimilation systems; evaluate impacts on coupled forecasts of using different ocean general circulation models (OGCMs) and different assimilation systems (particularly on seasonal forecasts); and improve current ocean assimilation schemes to achieve practical and near-optimal implementations.

Task 971-00-002: **NASA Seasonal-to-Interannual Prediction Project: Study of Predictability and Forecast of the ENSO Phenomenon**

GEST Investigator: Augustin Vintzileos

Collaborators: Michele Rienecker (PI, GSFC), Max Suarez (GSFC), Siegfried Schubert (GSFC), Christian Keppene (SAIC), Chaojiao Sun (GEST)

Abstract

The key for implementation of a successful seasonal-to-interannual prediction system, such as that used in the Global Modeling and Assimilation Office (GMAO), is its ability to forecast the El Niño/Southern Oscillation (ENSO) phenomenon up to 12 months in advance. Successful ENSO prediction depends on two major elements: adequate modeling of the processes governing this phenomenon, and initialization of this model close to the observed state. Analysis of existing ENSO forecasts is then necessary to understand reasons for successes and failures, allowing not only for improving the system, but also for understanding the physics and predictability of Earth's most important climate variability mode.

Description of Research

The GEST investigator leads two efforts in the NASA Seasonal-to-Interannual Prediction Project (NSIPP) effort in the GMAO. The first is the analysis of the ENSO forecast, conducted quasi-operationally, to understand reasons for successes and failures. The latter can be attributed to inadequacies of the model, incorrect initialization, and ENSO predictability issues. The second effort under this task involves validating simulated tropical variability with the GMAO coupled ocean-atmosphere model. Several sets of atmospheric and oceanic observations are used. The effort focuses on understanding (and eventually correcting) formulation inadequacies when problems in the simulated climate are detected.

Accomplishments during the Reporting Period

There were two major accomplishments in the research work on validating tropical variability simulated by the GMAO coupled model. First, the narrow meridional extent of the spatial structure of ENSO, a systematic bias that has plagued most coupled models since the inception of coupled modeling, was attributed to stronger-than-observed trade winds to the north and south of the Equator during warm ENSO events. This systematic bias, which tends to decrease sea surface temperature (SST) and, thus, narrows the meridional extent of ENSO, was also found in simulations with the forced atmospheric model. Experiments have been designed to assess the impact of cumulus friction on this systematic bias. The second major accomplishment came from the investigation of variability simulated by the GMAO coupled model in the Indian Ocean. This research was conducted as the thesis work of a student from the École Polytechnique in Paris, France, performed under the direction of the GEST investigator, for which he received an award for Outstanding Mentoring from GEST. The conclusion of this research was that stronger-than-observed mean annual convection in the eastern tropical Indian Ocean is responsible for a shallower-than-observed mean thermocline, which facilitates coupled interactions, and thus explains stronger and more frequent-than-observed variability there.

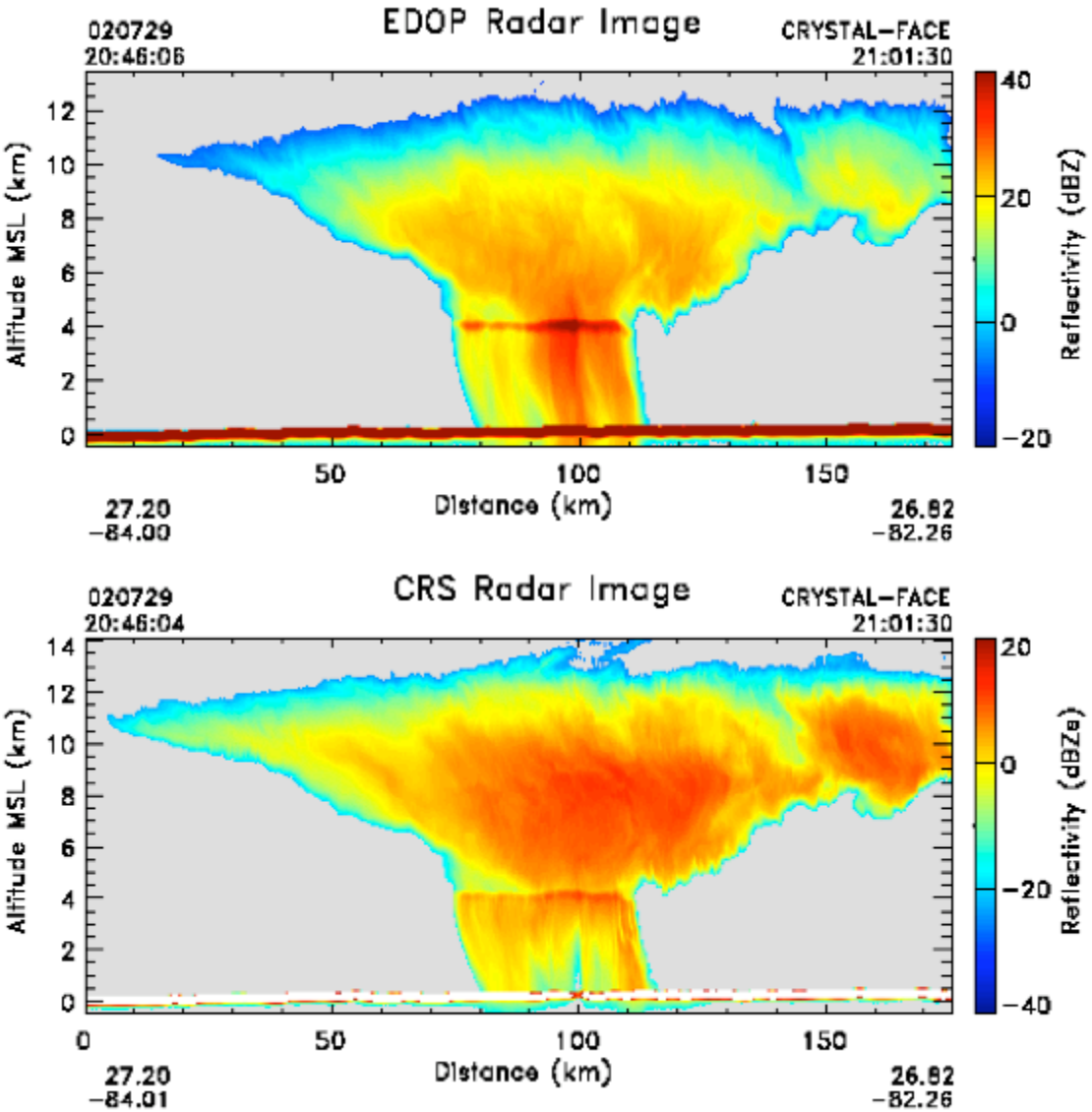
A major accomplishment regarding research on ENSO predictability and prediction came from the analysis of quasi-operational forecast of ENSO with the GMAO system for the period from 2000 to 2003. While forecasts with this system from 1993 to 2000 demonstrate very good skill, *i.e.,* the anomaly correlation at lead times of 9 months is 0.6, this skill drops significantly for forecasts after 2000. Analysis of these forecasts indicates that the poor skill is due to ENSO predictability issues, ranging from decadal variations of its characteristics to high frequency events, such as the Madden-Julian Oscillation and westerly wind bursts. Another major finding from this research came from the analysis of forecasts from 1993 to 2000, which showed that the so-called "spring predictability barrier" should not exist—at least,

not during major ENSO events, such as the one that took place from 1997-98.

Objectives for the Coming Year

The coming year will be dominated by three major research efforts. The first will be to alleviate biases in the narrow meridional pattern of simulated ENSO events and the intensity of organized convection in the Indian Ocean. Initial experiments with cumulus friction parameterization gave some mixed results and ideas for further experiments. The second will be to quantify patterns responsible for the drop in ENSO forecasting skill after 2000, and to investigate their predictability. Third will be to develop methods to generate ensemble forecasts that increase the skill of ENSO forecasts.

Cloud Modeling Research Group



Convective storm radar reflectivity images obtained by the NASA GSFC ER-2 Doppler Radar (EDOP, top panel) and Cloud Radar System (CRS, bottom panel) during the NASA Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) on 29 July 2002. Radar measurements show the sea surface return at the 0 km altitude and the melting layer at about 4 km above the sea level.

Figure provided by Lihua Li

Cloud Modeling Research Group

The GEST Center Cloud Modeling Research Group (CMG) seeks to understand the formation of cloud systems and their impact on climate change and weather forecasting. The scientists collaborate with GSFC investigators and researchers from other institutions, conducting research on cloud physical and dynamic properties, structure, and evolution, at synoptic to micro scales. Research activities focus on cloud system observation, analysis, modeling, and remote sensing of precipitation.

Several CMG scientists have developed and maintained the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model), and have used it as a tool to understand the physical process of convection. X. Li has incorporated an explicit bin microphysical scheme into the GCE to study the impact of increased aerosol concentrations on mesoscale convective systems. D. Johnson and C. L. Shie have performed simulations of convective activity over tropical and midlatitude environments to study atmospheric heating and moisture budgets, precipitation, cloud microphysics and dynamics, surface fluxes, and radiation processes. X. Zeng has scientifically improved model performance with a new representation of moist thermodynamics. Aiming to improve the precipitation forecasting, a four-dimensional variation data assimilation system was developed by Z. Pu to assimilate Tropical Rainfall Measuring Mission (TRMM) satellite data into the MM5 model. R.F. Lin, using a one-dimensional model with bin microphysics, investigated a special type of cirrus that was forced by the synoptic system. The impact of different nucleation processes on cloud microphysics and optical properties were examined.

In 2003 several scientists in the group conducted observational and numerical studies to understand the interactions between cloud systems—such as occur in hurricane, tropical cyclone, or other convective systems—and the large-scale environment. Specific topics include G. Gu's study of the connection of Atlantic hurricane activities and Africa easterly wave; an understanding of the organization and evolution of mesoscale convective systems through South China Sea monsoon, performed by J. J. Wang; and L. Wu's numerical study on the relationship between tropical cyclones and large-scale circulation.

Several other CMG scientists performed retrievals and/or estimates of a variety of cloud properties using both active and passive instruments. Studies using active instruments include L. Li's calibrating the 94 GHz cloud radar, and combining W-band radar, X-band radar, and lidar measurements to estimate cloud particle size and water content; L. Tian's developing dual-wavelength algorithms to estimate drop size distribution, attenuation, and vertical motion; and retrieving raindrop size distributions, done by K. S. Kuo, using a dual-frequency (Ku/Ka-band) precipitation radar. Retrievals using both passive and active observations include the use of the radar and multi-frequency radiometer observations by M. Grecu to estimate vertical precipitation profiles.

This brief summary and the detailed reports that follow demonstrate that the GEST Cloud Modeling Group is active in a variety of research topics of significant interest to the global climate change and hydrological science communities, who have been made abundantly aware of the work by copious publications in peer-reviewed journals, participation in conferences, and presentations at seminars.

Lin Tian and Chung-Lin Shie

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Task 912-02-027: **Analysis of Dual-wavelength Doppler Radar Measurements: Retrieval of Rain Drop Size Distribution and Attenuation**

GEST Investigator: Lin Tian

Collaborator: Gerry Heymsfield (PI, GSFC)

Abstract

Research performed during the past fiscal year focused on two major activities: Continuing analysis of dual-wavelength airborne Doppler radar measurements, and developing an algorithm to retrieve raindrop size distribution and attenuation. A distinction from past studies in this area is that the emphasis for this project is to include differential Doppler velocity in addition to reflectivity at the two wavelengths. The advantage of using differential Doppler velocity is that it is not affected by attenuation or vertical air motion, so the median drop size can be estimated directly from the differential Doppler velocity. The algorithm was applied to observations from the Cloud Radar System (CRS) at 3mm (94 GHz) and the ER-2 Doppler Radar (EDOP) at 3.2cm (10 GHz) during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE) field campaign.

Description of Research

The goal of this research is to develop an algorithm to estimate the drop size distribution (DSD) and vertical attenuation profile of stratiform precipitation. Raindrop size distribution and microwave attenuation are important for various applications, including improving rainfall measurement and understanding precipitation processes. The Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) provided useful information on rainfall distribution in the Tropics for weather and climate research. However, one of the uncertainties in the retrieval of the rainfall rate from single-wavelength radar is the unknown DSD. A dual-wavelength radar, such as the one proposed for the Global Precipitation Measurement (GPM) mission can provide DSD information and, hence, improve the accuracy of rainfall estimation. Airborne dual-wavelength Doppler radar observations from the 94-GHz CRS and the 10 GHz EDOP radar during the CRYSTAL-FACE field campaign provide an excellent opportunity to test the dual-wavelength technique.

Accomplishments during the Reporting Period

In the past year, research focused on developing and validating a dual-wavelength algorithm to estimate DSD and attenuation in precipitating clouds. A simple approach was developed, using data from EDOP and CRS. In this approach, differential Doppler velocity and reflectivity at 10 GHz was used to estimate DSD with an assumption that drop size is exponentially distributed. In the absence of detailed aircraft-based DSD measurements, research efforts were to compare the path-integrated attenuation from a surface reference. That can be directly measured with estimated attenuation. Some disagreement in outcomes was found; this is attributed to two possibilities: In the first case, the raindrop size distribution may not be exponential. Considerable effort is devoted to the impact of the DSD shape (the so-called μ) on the retrieved parameters. It was found that $\mu=1$ is a more reasonable assumption than the initial approach. In the second case, the attenuation by water vapor may not be accounted for properly. In early analyses, clear atmospheric sounding (which has much lower relative humidity than stratiform clouds) was used to estimate atmospheric attenuation. This may have contributed an error of about 2.5 dB in the attenuation estimate. It can also affect the estimated DSD. An effort is underway to correct the relative humidity in the sounding measurements.

To test some aspects of algorithm development, research also focused on data analysis, especially the Doppler velocity at 94 GHz, to make sure that aircraft motion and folding is properly corrected. Other work under this task resulted in processing the CRS and EDOP data for distribution to the broader scientific community.

Objectives for the Coming Year

The GEST investor will continue to improve the algorithms with a more-realistic drop size distribution, concentrating on the physical interpretation of the estimated DSD and vertical air velocity, and estimating attenuation in the melting band. Error analysis will be performed for the retrieval technique.

Task 912-02-029: **Application of Satellite Observations, Numerical Modeling, and Data Assimilation to Understand and Predict Mesoscale Precipitation Systems**

GEST Investigator: Zhaoxia Pu

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

Work performed under this task involves the application of satellite observations, numerical simulations, and data assimilation to studies of mesoscale precipitation systems. During the past year, progress has continued on assimilating satellite-derived surface precipitation data into a mesoscale model. To better assimilate precipitation data, studies have been conducted to investigate the quality of merged multisatellite precipitation data. To date, characteristics of hurricane precipitation structure have been assessed. In addition, initial conditions from different large-scale analysis are applied for Mesoscale Model version 5 (MM5) simulations to examine the sensitivity of model initial conditions to precipitation simulations. Finally, work has also been done to apply the mesoscale numerical model in support of studies on regional pollution due to aerosols and ozone.

Description of Research

Precipitation systems are key components of mesoscale studies and for numerical weather forecasting. The recent availability of increased amounts of satellite and remotely sensed data offers great opportunity to improve the understanding and forecasts of mesoscale precipitation systems. Assimilation of satellite-based and other remotely sensed rainfall data usually improves model initial conditions and subsequent forecasts. The results of mesoscale numerical simulations and forecasts can be validated by remotely sensed observations and can also be used as complementary information to better understand the structure and dynamics of mesoscale systems.

Accomplishments during the Reporting Period

Based on the Pennsylvania State University/National Center for Atmospheric Research (NCAR) Mesoscale Community Model (MM5) and its adjoint system, the investigator created a four-dimensional variational data assimilation (4DVAR) system that is capable of assimilating multitime observations into the MM5 model. In the past year, research has been continued to further develop the system to assimilate multisatellite precipitation data from NASA's Tropical Rain Measuring Mission (TRMM) into the 4DVAR system.

The TRMM multisatellite precipitation data set is a combination of microwave (TRMM Microwave Imager (TMI) and Special Sensor Microwave Imager (SSM/I data)) and infrared (IR)-determined estimates. The data set is available in real-time for three-hourly intervals at quarter-degree-by-quarter-degree resolution. Data assimilation experiments were conducted to assimilate these multisatellite data into MM5 model to improve qualitative precipitation forecasting (QPF). Preliminary experiments indicate that the 4DVAR results were very sensitive to the error characteristics of the precipitation data. To better understand the data quality and error characteristics, efforts were made to examine hurricane precipitation structure from TRMM real-time multisatellite data. In a collaboration with a summer student from the NASA Summer Institute on Atmospheric and Hydrospheric Sciences, two 2002 Atlantic hurricanes, Lili and Isidore, were chosen for study. This work showed that merged multisatellite data provided the general precipitation structure and

location of storms, and yielded several conclusions about tropical cyclone organization and spiral band patterning. Another conclusion was that periods of increasing precipitation rate corresponded with periods of increasing hurricane storm intensity. It was also found that microwave-based estimates are more accurate and detailed than infrared-based estimates. Infrared data are necessary to fill data gaps, as microwave estimates are not globally available. However, the error characteristic of each data type should be considered when applying the merged data to future applications and data assimilation.

Research was also conducted to examine initial condition sensitivity on mesoscale numerical simulations and forecasts. A series of mesoscale numerical simulations of Hurricane Bonnie (1998) was performed by using the MM5 model. The model initial and boundary conditions were derived from the global analysis generated by Goddard Earth Observing System (GEOS), National Centers for Environmental Prediction (NCEP), and European Center for Medium Range Forecasting (ECMWF), respectively. Results showed that all global analyses lead to consistent forecast results in terms of the hurricane intensity and track. However, significant differences were found in details.

In collaboration with Dr. Mian Chin in GSFC Code 916, the MM5 simulations were proposed to support a study of regional air pollution due to aerosols and ozone. During the reporting year, the investigator made progress towards generating long-term regional forecast databases, which are necessary for the offline chemical tracer transfer model. To verify the system, a two-week MM5 integration was performed for targeted areas in North America and East Asia. An offline tracer transfer model was modified for possible use in future applications.

Finally, the new community weather and forecasting model (WRF) and its data assimilation system are on the way to be implemented by NCAR, NCEP, and the university research community. As GSFC representative to the Weather Research and Forecasting (WRF) Data Assimilation Working Group, the GEST investigator has participated in WRF planning meetings, and was invited to join the NCEP's 3-DVAR working group.

Objectives for the Coming Year

Efforts will be continued on further detecting initial condition sensitivity to mesoscale forecasts of precipitation and applying the MM5/WRF model to support studies of chemical tracer transportation.

Task 912-02-036: **Physics of Cirrus Clouds and their Role in Global Climate**

GEST Investigator: Ruei-Fong Lin

Collaborator: D. O'C. Starr (PI, GSFC)

Abstract

Studies of cirrostratus clouds performed under this task use in-house, state-of-the-art, one-dimensional cirrus model to study the effects of homogeneous freezing and heterogeneous nucleation on the cloud bulk microphysical and optical properties. The study of cirrus outflow uses the Mesoscale Model version 5 (MM5) to simulate the 23 July 2002 case of the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment (CRYSTAL-FACE). The mesoscale model output was analyzed and compared with Next-Generation Radar (NEXRAD) data and *in situ* aircraft measurements to assess the simulation accuracy and to understand anvil evolution.

Description of Research

Two types of cirrus are parameterized by state-of-the-art general circulation models (GCMs): cirrostratus/stratiform ice clouds, generated by synoptic forcing, and cirrus anvil, formed by convective outflow in the upper troposphere. Recent cirrus parameterization [Karcher and Lohmann 2002] has advanced estimates of ice particle number concentration, as generated by

homogeneous freezing of aerosol particles. This parameterization is, however, based on parcel simulations, which are limited by their inherent assumptions. To simulate synoptically forced cirrus, a one-dimensional (vertical) framework is required. A cirrus episode on 16 January 1997 measured by lidar [Reichardt *et al.* 2002] was simulated and studied in detail using such a framework.

In addition to the cirrostratus study, the GEST investigator also worked on mesoscale simulations of the CRYSTAL-FACE 23 July 2002 case, which was formed by complex interaction of a preexisting outflow boundary, and lake and sea breeze fronts. One of the outstanding questions to be answered by results from this exercise is: if the mesoscale model captures the convective features reasonably well, does it also simulate the evolution of the anvil well? This question will be answered by rigorous comparison of model output with *in situ* aircraft measurements of the anvil.

Accomplishments during the Reporting Period

A series of numerical studies of synoptically forced cirrus were conducted to examine the sensitivity of cloud properties to a range of ice particle formation parameters and model spatial resolution. For the semi-ideal simulations studied here, three types of nucleation zones form. First, the nucleation responds to the initial moist layer. Second, a continuous cloud-top nucleation zone, which has not been captured by published results of similar numerical studies because of their coarse model resolution, corresponds to parcels above the initial moist layer achieving the nucleation threshold sequentially from the bottom-up. For the homogeneous freezing scenario, a model resolution as fine as 1 m is needed. The third zone type addresses intermittent mid-cloud nucleation zones, which form only when heterogeneous nucleation is included. These contribute to the formation of to 55 to 65% of the particles in the tested simulation range. The results demonstrate that the complicated structure of cirrostratus results solely from nucleation, particle growth, and sedimentation, and underscore the difficulty in parameterizing this type of cirroform cloud in GCMs. The depth of nucleation zone, usually much smaller than the vertical grid spacing for the upper troposphere in GCMs, has to be parameterized. Furthermore, satisfactory prediction of ice particles in the nucleation zone does not guarantee a good estimate of cloud properties in the cloud mass-bearing zone because of particle flux divergence inside the cloud.

For the 23 July 2002 case study from CRYSTAL-FACE, intense and persistent convective cells were formed south and northeast of Lake Okeechobee, Florida between 1630 and 2100 UTC. To evaluate the performance of a MM5-based postmission simulation using Eta analysis for initial and boundary conditions and Advanced Regional Prediction System (ARPS) reanalyses (where the ARPS assimilation used NEXRAD, sonde, and satellite data), these simulations are compared with observations, *e.g.,* cumulative rainfall estimated using the NEXRAD and NASA Polarimetric Radar (NPOL) rain maps and cloud and wind fields along the ER2 and WB57 flight paths. As expected, the assimilation captures the location and the timing of the convective events fairly well. However, ARPS reanalyses is not without weakness, as results show discontinuity in the cloud field at the time of data ingestion, excess width of the convective core, and longer system residence time than the observations show. MM5 simulation using North America Regional Reanalyses is underway. The evolution of the MM5-modeled cirrus outflow region has been estimated by tracking parcels released from the desired convective cores.

Objectives for the Coming Year

After more detailed evaluation of mesoscale simulations of the 23 July 2002 case, the evolution of mesoscale updraft in the anvil region will be described and used to drive a high-resolution cirrus model to examine whether the outflow is turbulent and the possibility of generation of ice crystals. The cirrus model will be modified by adopting optical properties for ice particles of distinct shapes [Yang *et al.* 2000] and an adjustable time-step scheme to forward microphysics integration over time.

Task 912-10-109: **Various Numerical Applications to Tropical Convective Systems Using a Cloud-Resolving Model**

GEST Investigator: Chung-Lin Shie

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

Research tasks performed during the reporting period consist of three major studies. Two of them focused on radiative-convective systems and their respective interactions with atmospheric large-scale environment, using numerical simulations obtained from the Goddard Cumulus Ensemble (GCE) model; the third involved a numerical study of model performance, based on the implementation of massively parallel programming (MPP) with a message passing interface (MPI) in the GCE model. In the first study, which used a somewhat idealized approach, the distribution of domain-averaged temperature and water vapor fields, obtained at the modeled tropical quasi-equilibrium states, were examined. In the second study, a small number of real tropical episodes, based on Tropical Rainfall Measuring Mission (TRMM) field experiments (*i.e.,* the South China Sea (SCS) Monsoon Experiment (SCSMEX; 1998) and the TRMM Kwajalein Experiment (KWAJEX); 1999) were simulated such that several major features, such as the rainfall amount, the Q1/heat and Q2/moisture budgets, and the modeled radar signatures (*e.g.,* reflectivity and vertical velocity) were investigated. The third study was designed to significantly improve GCE model performance, particularly the enhancement of model computational speed by equipping the model with an optimal MPI concept that uses massively parallel computing capabilities (provided by the GSFC supercomputer system) with multiple central processing units (CPUs).

Description of Research

In recent years, increasing attention has been given to cloud-resolving models (CRMs) for their ability to simulate radiative-convective systems, which play a significant role in determining the regional heat and moisture budgets in the Tropics. CRM's growing popularity can be credited to inclusion of realistic mechanism, such as explicit cloud-scale dynamics, sophisticated microphysical processes, and explicit radiative-convective interaction. The primary objective of this research, which involves a series of systematic numerical simulations using the GCE model (itself a CRM), is to better understand the role radiative-convective systems (clouds) have played in the hydrological (water and energy) cycle in climate systems by examining interactions between clouds and large-scale environmental components, such as horizontal wind fields, sea surface fluxes, and large-scale temperature and moisture forcing. There is a growing preference for a three-dimensional (3-D) CRM over a two-dimensional (2-D) CRM in the cloud modeling community because the former provides a numerical tool with an overall more-realistic physical structure than does the latter. The 3-D CRM, however, is a much more expensive tool (*i.e.,* it uses more CPU cycles—and, therefore, time) than its 2-D counterpart. An implementation of MPI in the 3-D GCE model to speed up model performance has, therefore, been conducted so that the presumably massive and expensive use of computational time can be greatly reduced.

Accomplishments during the Reporting Period

For task work in the first area of research, a series of systematic numerical experiments was simulated for a long period by varying imposed environmental components (*i.e.,* sounding data from the 1956 Marshall Island Experiment in Central Pacific) in a 2-D GCE model to produce various quasi-equilibrium thermodynamic states. Numerical results showed that the genesis of a warm/wet quasi-equilibrium state was largely due to either large surface fluxes or strong vertical wind shear, while a cold/dry quasi-equilibrium state was attributed to a remarkably weakened mixed-wind shear along with weak surface winds [Shie *et al.* 2003a]. In a follow-up study [Shie *et al*. 2004a], a simple—yet crucial—hydrodynamic concept generated a remarkable feature that

showed a quasi-linear distribution of domain-averaged water vapor and temperature fields obtained at the modeled tropical quasi-equilibrium states. However, and very unusually, this quasi-linear relationship between water vapor and temperature varied with the quasi-equilibrium state, *i.e.,* the slope of the quasi-linear relationship increased with temperature.

In the second area of research, soundings and large-scale forcing data from both SCSMEX (1998) and KWAJEX (1999) were applied in both the 2-D and 3-D GCE models to simulate the tropical convective systems. One major objective of the SCSMEX study was to better understand the key physical processes for the onset (18-26 May 1998) and post-onset (2-11 June 1998) phases of the SCS monsoon. The numerical results agreed well with observations in rainfall amount and its variation, as did the domain-averaged heat and moisture budgets. Surface evaporation from the ocean prior to the monsoon onset was shown to dominate after the monsoon onset, when rainfall increased [Tao *et al.* 2003a,b,c]. In the KWAJEX study [Shie *et al*. 2003b], three 1999 convective episodes were simulated, *i.e.,* 7-12 August, 18-21 August, and 29 August-13 September. The temporal variation of both 2-D and 3-D modeled rainfall also agreed fairly well with the diagnostic estimates from the combined radar and rain gauge data, findings that were similar to the SCSMEX cases. Such a good agreement may be due largely to the driving forcing, that is, the sounding-derived large-scale temperature and moisture tendencies that were implemented in the model. However, both 2-D and 3-D simulated rainfalls quantitatively showed a slight wet bias in all three episodes. Overall, the 3-D model had slightly better performance than the 2-D model in simulating both temporal evolution and total amount of rainfall. Further, the 2-D model generated more stratiform-type rainfall, while the 3-D model significantly favored convective-type rainfall.

The purely numerical task addressed by the third research area designed to speed up 3-D GCE model performance by means of implementing a MPI. A sensitivity study was performed that examined the performance of the two MPI-implemented codes (*i.e.,* compressible and inelastic versions) on three different computer system platforms [Juang *et al.* 2004a]. There were several major findings: Both versions achieved about a 99% speedup using up to 256 CPUs, but not for 512 CPUs. Also, the inelastic version seemed to perform better than the compressible version as measured by speedup and efficiency due to the larger amount of computation required in the former version.

In other work, the GEST Investigator collaborates with the Surface Flux Team (GSFC Code 912), the University of Virginia, Columbia University, the University of Washington, and the Japanese National Space Development Agency (NASDA).

Objectives for the Coming Year

Next year's research tasks will continue most of the projects detailed above, with particular emphasis on a project that will combine the second and third research areas, *i.e.,* a 3-D GCE model will be made "financially" possible (in terms of CPU cycles and real time) to explore the possibility of expanding its simulation territory into extratropical regions, and, perhaps, globally.

Task 912-10-116: **Multi-Day Cloud-Resolving Modeling Studies of Tropical and Midlatitude Convective Systems**

GEST Investigator: Daniel Johnson

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

Several multiday simulations of convective activity over tropical and midlatitude environments have been conducted using the cloud-resolving Goddard Cumulus Ensemble (GCE) model. These simulations were used in studies of atmospheric heating and moisture budgets, precipitation, cloud microphysics,

dynamics, surface fluxes, and radiation processes. Three-dimensional simulation data has been provided for inclusion into the Tropical Rainfall Measuring Mission (TRMM) retrieval algorithm database. Software for visualization has been developed, and comparisons have been made between 2-dimensional (2-D) and 3-dimensional (3-D) simulations for several cases. Results have been submitted for use in cloud modeling studies, with the goal of improving cloud parameterizations in climate models, and surface and radiation processes in cloud-resolving models (CRMs).

Description of Research

The physical complexity and nonlinearity of interactions between deep convective cloud systems and the large-scale environment is one of the key uncertainties in understanding climate change. Cloud systems largely influence atmospheric radiative and latent heating and air-surface interactions due to latent and sensible heat release. These processes must be better understood before global models can be substantially improved. A CRM, such as the GCE model, can be used to explicitly resolve and quantify the collective effects of cloud systems, and to examine the ways in which large-scale processes relate to the development, maintenance, and structure of deep convective clouds. The goals of this research are to further develop and use the GCE model to better understand tropical and midlatitude convective cloud systems, and to improve cumulus parameterizations in global models. Principal efforts include studies on the role of microphysical processes, surface fluxes, radiation, ice habits, and dynamical processes in the evolution of deep convective systems.

Accomplishments During the Reporting Period

The GEST investigator conducted several 2-D and 3-D multiday CRM simulations of convective systems in both tropical and midlatitude environments using the GCE model. The simulated systems utilized large-scale thermodynamic forcings diagnosed from the Tropical Ocean Global Atmospheres Coupled Ocean Atmosphere Response Experiment (TOGA-COARE; Pacific Ocean), the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE; Atlantic Ocean), and the Atmospheric Radiation Measurement (ARM; Oklahoma) program. GCE model data from these simulations were used to study the atmospheric heating and moisture budgets, microphysical processes, rainfall production, convective and stratiform separation, radiation and cloud feedbacks, and ocean/land surface processes in these environments. Thermodynamic, dynamic, and microphysical fields from these simulations were provided for incorporation into the TRMM retrieval algorithm database. Results from several TOGA-COARE GCE simulations examine the heating, moisture, and microphysical budgets, and the impact of model dimensionality, domain size, and model numerics on the simulated results [Johnson *et al.* 2002, 2004]. GCE simulated data, model code, 3-D figures, and animations were created and provided to individuals within GSFC and outside, including the National Oceanic and Atmospheric Administration (NOAA), the National Space Development Agency of Japan (NASDA), and Columbia University.

The GEST investigator was involved in implementing an updated radiation package into the 3-D GCE code, which improved results from prior multi-day simulations. In addition, major debugging of the 3-D model was undertaken to improve portability of the code. Programs were developed and/or improved upon to read in model data and to produce both 2-D and 3-D figures and animations.

Results from GCE simulations of convection during the ARM experiment were submitted to the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) Working Group 4 (WG4). The investigator is also co-leading an offline study to better understand radiation and surface processes in the CRMs participating in the GCSS WG4. So far seven modeling groups have submitted results for this study; further information can be found at: http://rsd.gsfc.nasa.gov/users/djohnson/gcsswg4.

Objectives for the Coming Year

Goals for the coming year include completing an offline study for models involved in the GCSS WG4. New studies will involve the comparison and investigation of 3-D and 2-D GCE multiday simulations of TOGA-COARE and GATE

convection, and 3-D ARM multiday studies of midlatitude storms. 3-D GCE simulations of different convective cases will also be provided for inclusion in the TRMM rain and latent heating retrieval algorithm databases.

Task 912-18-129: **Study of Tropical Cyclone Activities**

GEST Investigator: Liguang Wu

Collaborator: Scott Braun (PI, GSFC)

Abstract
Work performed under this task advances our understanding of tropical cyclone activities. Three research tracks support this work: studying environmental control of tropical cyclogenesis and tropical cyclone intensity change; exploring the possible impacts of global warming on tropical cyclone motion in the Atlantic basin; and determining the effects of hurricane-ocean interactions on tropical cyclone tracks and intensity. Atlantic tropical cyclogenesis was found to be controlled primarily by large-scale circulation. Results from the intensity change study suggest that the inhibiting effect of the large-scale environmental flow on intensity change results from induced hurricane asymmetries, while hurricane-ocean interactions affect tropical cyclone intensity mainly through induced symmetric ocean cooling with respect to its center.

Description of Research
Hurricanes, as key components of the global climate system, can be significantly affected by global climate change, and introduce feedbacks to the global climate system. Therefore, it is necessary to understand the mechanisms involved in the formation and intensity change of tropical cyclones. During the past year, particular emphasis has been placed on studying the interactions between the large-scale environment and tropical cyclone activity, primarily through numerical experiments using the Tropical Cyclone Model version 3 (TCM3), a coupled hurricane-ocean model, and the community mesoscale model version 5 (MM5).

Accomplishments during the Reporting Period
During the past year, environmental controls on tropical cyclogenesis and intensity change were investigated to examine the possibility of extended numerical prediction of tropical cyclogenesis. Extended simulations are conducted using the state-of-the-art MM5 model by feeding the coarse-resolution re-analysis from the National Centers for Environmental Prediction (NCEP) as initial and lateral boundary conditions. The control experiment was integrated from 0000 UTC, 1 September to 1200 UTC, 30 September 2001, during which time four tropical cyclones were observed to occur over the Atlantic Ocean and the Gulf of Mexico. The simulated tropical cyclones were detected with criteria based on observations. Although an extratropical cyclone was generated in the control run, the observed cyclones were all reasonably simulated in the control experiment in terms of the formation location and time; the simulated tracks were also comparable to the observed. Since tropical cyclones involve processes with time and space scales ranging from those associated with cumulus convection to those associated with variations in the general circulation, the simulated tropical cyclogenesis was sensitive to model physics, including initial conditions. However, in general, ensemble predictions with various model physics options converge to the observation. The numerical experiments conducted in this study provide numerical evidence that individual tropical cyclogenesis is largely controlled by large-scale circulation.

The tropical cyclone intensity study was conducted using numerical modeling with three numerical models. First, a hydrostatic primitive equation model (TCM3) was used to investigate the roles of environment-induced asymmetries in simulated hurricane intensity. In these idealized experiments, the hurricane asymmetries resulted from uniform flow, vertical shear, and the beta effect. Second, a coupled hurricane-ocean model

was used to examine the influence of air-sea coupling on hurricane intensity. The symmetric component of the resulting sea surface temperature (SST) anomaly with respect to the tropical cyclone center was found to dominate the negative feedback. Finally, MM5 was used to simulate Hurricane Erin (2001). The simulations have been validated with Convection and Moisture Experiment (CAMEX)-4 observations and Tropical Rainfall Measuring Mission (TRMM) data. The vertical wind shear was found to significantly reduce Erin's intensity by inducing wavenumber-1 components in the vicinity of the radius of maximum wind, which can weaken the radial circulation, the tangential wind, and the convective activities of the eye wall.

A study to assessing the impacts of global warming on tropical cyclone tracks was also conducted for the Atlantic basin, using a new approach that was earlier proposed by the GEST investigator. The approach is based on the premise that future characteristics of tropical tracks are primarily determined by changes in large-scale steering flows. These characteristics can be derived from the climatological mean velocity of tropical cyclone motion by using a trajectory model. The future motion velocity, composed of the large-scale steering and the beta drift, is determined with the output of the Geophysical Fluid Dynamics Laboratory (GFDL) R30 climate model. Preliminary results indicate that the influence of global warming on the Atlantic tropical cyclone tracks is not significant, but if the formation locations are shifted as a whole, the tropical cyclone tracks can differ significantly from the prevailing tracks.

Objectives for the Coming Year

In the next year, the GEST investigator will continue efforts to understand tropical cyclone activities, with the main focus on formation of tropical cyclones and their environmental controls.

Task 912-19-131: **Cloud Radar Calibration, Data Analysis, and Instrument Development for Studies of Hurricane Genesis**

GEST Investigator: Lihua Li

Collaborator: Gerry Heymsfield (PI, GSFC)

Abstract

Research has concentrated on calibrating the GSFC Cloud Radar System (CRS), radar data processing and analysis for retrieval of cloud microphysical properties, and developing of an airborne X-band radar/scatterometer to study the genesis of hurricanes. Accuracy of 1 dB was achieved in CRS calibration using a trihedral corner reflector and ocean-surface returns. This result was verified by intercomparing CRS measurements with the well-calibrated ER-2 Doppler Radar (EDOP) and the University of Massachusetts' Cloud Profiling Radar System (CPRS). The analysis of CRS ocean-surface return from the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRSYSTAL-FACE) showed that the quasispecular surface scattering model works well at 94 GHz. This result supports the prospect of using the ocean surface as a calibration reference for airborne and spaceborne millimeter-wave cloud radars. By combining radar and lidar measurements, cloud particle size and water content have been retrieved. This provides a more complete structure of cloud images and cloud microphysical properties. Flying a X-band radar/radiometer on a high-altitude, long-endurance Global Hawk Unmanned Aerial Vehicle (UAV) will enable key measurements to be obtained off the east coast of Africa. These measurements will help scientists to better understand how hurricanes develop and which of them may eventually threaten the coastal U.S.

Description of Research

The GEST investigator's research efforts involve remote sensing instrument development, data processing, data analysis, and cloud microphysical properties retrieval using radar measurements. Instrument-related efforts include developing the

CRS radar hardware, and integration and test flights on a NASA ER-2 aircraft, system calibration, and field experiments. Other work includes developing a new X-band radar/scatterometer in support of NASA's Atlantic Seeding Hurricanes Experiments (ASHE). Data processing and data analysis research includes cloud particle size and water content retrieval using combined 94 GHz and 9.6 GHz radar and cloud lidar measurements, and analyzing CRS backscattering signals from the ocean surface and comparing the results with a quasispecular ocean-surface scattering model.

Accomplishments during the Reporting Period

Radar calibration is crucial to ensure the quality of data obtained from several sensors. However, calibration of millimeter-wave radars is not a trivial task. The delicate nature of millimeter-wave components and the harsh environments in which they operate may cause undetected performance changes unless regular system calibration is performed. Research efforts involve continual analysis of CRS calibration and intercomparison data, verifying calibration results using EDOP data and ocean surface returns obtained from the CRYSTAL-FACE. The calibration uncertainty for CRS was found to be 1 dB, which is excellent for an airborne 94 GHz cloud radar.

Research efforts also contributed to the development of CRS data processing code. CRS is a new instrument in the research community. Most of its data processing code was developed after the CRYSTAL-FACE experiment. The nature of backscatter and propagation of the 94 GHz signal is significantly different from those from lower-frequency radar signals. Special effort must be made to averaging of the data and noise subtraction to improve radar sensitivity, atmospheric attenuation, and navigation corrections. To this end, CRS data have been completed, processed, and widely shared with the research community, including scientist from the Colorado Sate University, Harvard University, the University of Utah, the National Center for Atmospheric Research (NCAR), NASA Langley Research Center, and GSFC.

The ocean surface has been widely used as a calibration target for airborne and spaceborne microwave sensors. However, at millimeter-wave frequencies the mechanism of ocean surface backscattering is still not well understood, due to the lack of experimental measurements. During the CRYSTAL-FACE, measurements of ocean surface scattering were made using CRS. The relationship between the normalized ocean surface cross section and the incidence angle at different wind conditions was derived. Analysis of the radar measurements shows very good agreement with quasispecular models. This unprecedented dataset enhances our knowledge of the mechanism of ocean surface scattering at 94 GHz, and provides a valuable reference to develop a real-time calibration algorithm for airborne millimeter-wave cloud radars and for the ongoing NASA CloudSat mission, which will utilize a 94 GHz spaceborne cloud radar for global ice cloud measurements.

CRYSTAL-FACE aimed at gaining an improved understanding of the global ice water and water vapor fields in the upper troposphere and their relationship with global radiative fields, and improved understanding of the dynamical and radiative processes that produce these clouds. As one of the six aircraft operated during CRYSTAL-FACE, the ER-2 carried a full suite of sensors, including the CRS, the Cloud Physics Lidar (CPL), and the 9.6 GHz EDOP. The remote sensing data collected by this ensemble of instruments is unprecedented and enables studies of cloud microphysical properties using different approaches. To this end, analysis work has concentrated on retrieval of cloud particle size and water content by combining data from W-band radar (from CRS), X-band radar (from EDOP), and lidar (CPL) measurements.

The GEST investigator has been the lead engineer in developing a low-cost, miniaturized, lightweight, X-band (9.3 GHz), Doppler radar for operation on a Global Hawk UAV. The NASA ASHE proposal effort is underway at GSFC to provide instrumentation for the high-altitude (65kft) Global Hawk UAV to study the genesis of hurricanes off the east coast of Africa. During the Atlantic hurricane season, waves frequently come off the African continent; about one-tenth of these develop into hurricanes that eventually may threaten the coastal U.S. Key parameters that help determine whether or not a specific wave develops

into a tropical storm are the ocean surface winds and sea surface temperatures. Current satellite precipitation and wind sensors (*e.g.,* the Tropical Rainfall Measuring Mission (TRMM), QuickScat, the Advanced Microwave Scanning Radiometer (AMSR), etc.) have resolutions that are too low and revisit times that are too infrequent to study this problem. Aircraft sensors with higher spatial resolutions and more-frequent sampling are desired. Unfortunately, tropical storm genesis frequently occurs in the 5000-km region between the outer Caribbean Islands and Africa. The Global Hawk is the only UAV and aircraft that is capable of flying in this region for an extended period (24-48 hours) and with a large payload (2000 pounds). Instruments for this promising UAV are required; it will be necessary to miniaturize and reduce costs of current aircraft radars and radiometers to fit within the UAV's payload and performance envelope.

Objectives for the Coming Year

In the coming year, research will concentrate on developing the UAV X-band radar/scatterometer instrument. A marine radar transceiver has been purchased and will be modified for the nadir-pointing subsystem. The data system will use a commercial off-the-shelf digital receiver board and a single-board computer to achieve data recording and processing. The radar transmitter and positioner will be designed and developed for the conical scanning subsystem, as well. The CRS hardware will be upgraded, including using a larger antenna to improve sensitivity. The analysis of ocean surface data returns will continue, as will data analysis and cloud particle and water content retrieval using radar and lidar measurements. The CRS will be field deployed to support the GSFC Code 975 research program, "Improvement to the Conical Scanning Submillimeter-Wave Imaging Radiometer (CoSSIR)."

Task 912-21-140: **Precipitation Estimation from Satellite Active and Passive Microwave Observations**

GEST Investigator: Mircea Grecu

Collaborator: Robert F. Adler (PI, GSFC)

Abstract

A technique for estimating vertical precipitation profiles from multifrequency, multiresolution, active and passive microwave observations has been developed during the past year. The technique is applicable to the Tropical Rainfall Measuring Mission (TRMM) observations. It is based on models that simulate high-resolution brightness temperatures as functions of observed reflectivity profiles, and a parameter related to the rain drop-size-distribution (DSD). The modeled high-resolution brightness temperatures are used to determine normalized brightness temperature polarizations at the resolution of the microwave radiometer. An optimal estimation procedure was employed to minimize the differences between the simulated and observed normalized polarizations by adjusting the DSD parameter. The impact of other unknowns that are not independent variables in the optimal estimation but affect the retrievals is minimized through statistical parameterizations derived from cloud model simulations. The technique appears to be superior to single-instruments retrievals.

Description of Research

Precipitation estimation from satellite observations is subject to various uncertainties. An important part of these uncertainties originates in the variability of the precipitation particle size distribution within the instrument field of view. This variability precludes the existence of one-to-one relationships between satellite observations and precipitation variables. This mathematical indeterminacy may be addressed by using additional, statistically derived (yet physically based) relationships that reduce the number of independent variables to be determined to the number of available observations. These relationships, although valid in a statistical sense, may still lead to large errors in instantaneous precipitation estimates at small spatial scales (*i.e.,*

on the order of kilometers). The simultaneous use of information from various instruments alleviates this problem, because more accurate statistical relationships can be derived. In this research a combined approach to estimate precipitation from radar and radiometer satellite observations was investigated. This approach is superior to either radar-only or radiometer-only precipitation estimation algorithms because it allows for a more rigorous estimation of the precipitation DSD, which is determined from the condition of consistency of radar-predicted brightness temperature with radiometer-observed brightness temperature. The approach was applied to TRMM data and the results were analyzed.

Accomplishments during the Reporting Period

The combined retrieval technique was investigated using TRMM observations collected during the Kwajalein Experiment (KWAJEX). These observations cover an area extending from 5° N to 12° N latitude and 166° E to 172° E longitude from July to September 1999, and are coincident with various ground-based observations, facilitating a detailed analysis of the retrieved precipitation. Using the method developed during this research, precipitation estimates consistent with both passive and active TRMM observations were obtained. Various parameters characterizing these estimates, *i.e.,* rain rate, precipitation water content, DSD intercept, and the mass-weighted mean drop diameter, were found to be in good qualitative agreement with independent experimental and theoretical estimates. Combined rain estimates were in general higher than the official TRMM Precipitation Radar (PR)-only estimates for the area and the period considered in the study. This evidence, together with the fact that the relationships between brightness temperatures and precipitation are quite simple for low frequencies and are significantly more sensitive to the total extinction in the atmospheric column sampled by the radiometer than to the vertical distribution of precipitation in that column, suggest that combined approach rain estimates are likely to be more accurate than TRMM PR estimates alone. A sensitivity analysis revealed some dependency of the combined retrievals on the choice of covariance matrices (the matrices indicating the confidence in the radar and radiometer observation and simulation models). However, this dependence was smaller than that of PR-only retrievals, which justifies the use of combined retrievals even if uncertainties in the covariance matrices are suspected. Ground-based precipitation estimates, derived from an analysis of rain gauge and ground radar data, were in better agreement with the combined estimates than with the TRMM PR-only estimates, which suggests that information useful for improving the radar-only estimates is contained in the brightness temperature data.

Objectives for the Coming Year

Work in the coming year will focus on large-scale application of the combined approach to TRMM data. In addition, a procedure will be developed to estimate hydrometeor latent heating from retrieved precipitation profiles. Hydrometeor latent heating from spaceborne instruments is an important topic of research because various applications require knowledge of the spatial and temporal distribution of heating in the Tropics. These applications range from long-term climate prediction to storm-scale diagnostics and forecasting. The use of precipitation profiles derived from the combined precipitation estimation algorithm may provide additional information regarding latent heating distribution in the Tropics because the precipitation profiles are indicative of the processes taking place in the clouds. For example, a decrease in precipitation towards the ground may indicate evaporation, while an increase could be caused by condensational/depositional growth and collision-coalescence. Nevertheless, accurate precipitation profiles, such as those derived by the combined technique, are required in precipitation latent heating estimation.

Task 912-21-145: **Tropical Rainfall Measuring Mission Project Science**

GEST Investigator: Guojun Gu

Collaborators: Robert F. Adler (PI, GSFC), George J. Huffman (SSAI), Scott Curtis (JCET and East Carolina University), and Adam H. Sobel (Columbia University)

Abstract

This research effort dealt primarily with the evaluation and scientific applications of the currently archived Tropical Rainfall Measuring Mission (TRMM) products. Surface rain gauge data were used to validate and evaluate the TRMM rainfall product. Some preliminary comparisons were conducted over the North American continent against surface rain gauge data obtained from the Climate Prediction Center (CPC) at the National Oceanic and Atmospheric Administration (NOAA). The high-quality, high-resolution TRMM products were used to quantify African easterly waves and their related convection and rainfall, and to provide a detailed account of the West African Monsoon system. This research is directly related to understanding African climate and Atlantic hurricane activity.

Description of Research

African easterly waves can effectively modulate rainfall variability over the West African continent during the summer season, and may evolve into tropical storms when they move into the Atlantic Ocean. The first objective of this study is to quantify whether there is any significant interannual variability in the waves relating to their close association with Atlantic hurricanes. The second objective is to examine how these waves interact with deep convection phenomena. Since these waves generally follow the evolution of the West African monsoon, the third objective is to investigate the nature of the fundamental mechanisms, and how the large-scale monsoon system modulates the wave structure and strength.

Accomplishments during the Reporting Period

African easterly waves (AEWs) are quantified by conducting a 2-D wavelet analysis of a five-year TRMM rainfall product. The waves can effectively modulate surface rainfall patterns during boreal summer, particularly along the Intertropical Convergence Zone (ITCZ). Evident interannual variability exists not only in these waves' strength, but also in their spectral properties, *i.e.*, dominant frequency and wavenumber ranges. Furthermore, these variabilities can partly be ascribed to year-to-year variations of their embedded large-scale environment, especially the status of African Easterly Jet (AEJ). Generally, a stronger (weaker) AEJ indicates a stronger (weaker) disturbance activity season. These results may enhance our understanding of persistent African drought by examining easterly wave activity.

The interaction between AEWs and convection is further examined through a 1-D wavelet cross-spectrum analysis of rainfall and wind fields. Two distinct phase relationships are discovered between the regions south and north of about 12.5^{o} N. In the southern West Africa, roughly along the mean latitudes of the ITCZ, most rainfall occurs near the wave trough zone, suggesting a role for convective heating in the waves. In the northern part, however, rainfall is primarily observed directly behind the southerly wind maximum, close to the wave ridge, suggesting a minor or even negative impact on the waves. Thus, the wave-convective coupling is strongly latitude-dependent, as is waves' horizontal structure. This latitude-dependence might provide important clues in exploring the relationship between wave activity and the Atlantic hurricanes, since more intense and moist waves may more easily evolve into tropical cyclones.

Major mean rainfall over West Africa tends to be concentrated in two regions and is observed in two distinct seasons, manifesting an abrupt shift of the mean rainfall zone during June-July. Near the Gulf of Guinea (about 5° N), intense convection and rainfall are seen during April-June and roughly follow the seasonality of sea surface temperature (SST) in the tropical eastern Atlantic. Along the latitude of about 10° N over the interior West

African continent, a second intense rain belt begins to develop from July and remains there during the later summer season. This belt appears with a northward-moved AEJ and its accompanying horizontal and vertical shear zones, the appearance and intensification of an upper tropospheric Tropical Easterly Jet (TEJ), and a strong low-level westerly flow. Westward-propagating wave signals dominate synoptic-scale variability during July-September, in contrast to the evident eastward-propagating signals during May-June. The abrupt shift of the mean rainfall zone thus turns out to be a combination of two distinct physical processes: Evident seasonal cycles in the tropical eastern Atlantic Ocean, which modulate convection and rainfall in the Gulf of Guinea by means of SST-related forcing; and the interaction among the AEJ, TEJ, low-level westerly flow, moist convection and waves during July-September, which modulates rainfall variability in the interior West Africa, primarily within the ITCZ rain band.

Objectives for the Coming Year

Interannual-to-interdecadal climate variability in the tropical Atlantic sector is a very important topic that is directly associated with improving climate forecasts and diagnosis in the Atlantic basin and for neighboring continents. Detailed physical patterns that generate this variability, particularly for rainfall, are not clear and have yet to be quantified. Work on this topic will continue, using TRMM products and other satellite observations. A near-real-time TRMM product (3B42rt) provides much higher quality, and spatial and temporal resolution rainfall information than all of the previously archived satellite datasets. To ensure that the product has a higher quality, thereby making it eligible for application in various scientific investigations, ground-based validations are necessary and urgent. During the next few years, detailed ground validations will be conducted over both Australian and North American regions and may extend to other midlatitude regions, depending on the availability of surface rain gauge data.

Task 912-23-147: **Global Precipitation Mission Physical Radiative Transfer Model**

GEST Investigator: Kwo-Sen Kuo

Collaborator: Eric Smith (PI, GSFC)

Abstract

Error characterization and algorithm validation for the Global Precipitation Measurement (GPM) mission were addressed during this reporting period. The work involved developing a new mathematical-physical framework to retrieve raindrop size distributions using a dual-frequency precipitation radar. A defined triad of parameters was found to predict the mean Doppler velocity in calm air. When used in combination with the first moment of the measured Doppler spectrum, one can further estimate the updraft and, in turn, incorporate the updraft into estimation of in-cloud rain mass flux. This is an improvement over the current methods that do not take this factor into account. Other work on analysis of Tropical Rainfall Measuring Mission (TRMM) products provided insights into discrepancies between different rain rate retrieval algorithms that should allow improvements to these algorithms. A more thorough analysis is currently underway.

Description of Research

The GPM mission will consist of a core satellite and several constellation satellites. The core satellite will be equipped with a dual-wavelength rain radar and a microwave radiometer, while the constellation satellites will have only radiometers onboard. This is an ambitious mission, aimed at furthering our understanding of the global water cycle. The mission requires quantitative error characterization and algorithm validation to ensure its success. An advanced three-dimensional physical radiative transfer (PRT) model that incorporates realistic hydrometeor information is an important and integral part of the validation effort. Furthermore, it is desirable for this PRT model to carry a solution for time-dependent point sources to simulate illumination by a spaceborne

radar. The physical radiative transfer model will take as input hydrometeor profile measured by a Doppler profiler, temperature/humidity profile measured by radiosonde, and surface emissivity measured by a downward-pointing multispectral radiometer. The hydrometeor profiles will be adjusted within the Doppler profiler's error range to determine the closest match between the model-simulated radiances and those measured by a downward-looking radiometer and radar from the space platform. The resultant mismatch between simulation and measurement will characterize the background bias uncertainty. The difference between any retrieval algorithm's hydrometeor solution and the error model solution will define the current retrieval bias.

Accomplishments during the Reporting Period

A new mathematical-physical framework for the retrieval of raindrop size distributions using a dual-frequency (Ku/Ka-band) precipitation radar was developed, in which effective radius and effective variance of the size distribution along with liquid water content were proposed to form the parameter set that best specifies drop size distribution (DSD) and the related rain rate parameter. Both the equivalent reflectivity factor and specific attenuation are accurately determined by this set of parameters, in which the influence of DSD on the two radar parameters becomes inconsequential. These therefore provide a more robust basis for radar rainfall retrieval than methods based on *ad hoc* Z-R and K-R relationships or methods based on specific DSD models. Furthermore, this triad of parameters nicely predicts the mean Doppler velocity in calm air. Using this parameter along with the first moment of the measured Doppler spectrum, one can further estimate the updraft and in turn, incorporate the updraft into the estimation of in-cloud rain mass flux. This is an improvement over current methods that do not take this factor into account.

On a different task, preliminary analysis of TRMM version 6 products was carried out. The analysis provided insights into the discrepancies between different rain rate retrieval algorithms (*i.e.,* 2A12, 2A25 and 2B32). These insights would, in turn, support improvements to these algorithms. A more thorough analysis is currently underway.

Objectives for the Coming Year

In the next reporting period, development of a three-dimensional microwave radiative transfer model will be finalized, incorporating realistic hydrometeor composition and morphology. The new radiative transfer model will be incorporated into the Nonhydrostatic Mesoscale Model (NMS). Links between storms' morphological structure to microphysical properties will be investigated.

Task 912-29-152: **Impact of Aerosols On Midlatitude and Tropical Storms: A Model Study**

GEST Investigator: Xiaowen Li

Collaborator: Wei-Kuo Tao (PI, GSFC)

Abstract

The Goddard Cumulus Ensemble (GCE) model was incorporated into an explicit bin microphysical scheme to study the impact of increasing aerosol concentration on mesoscale convective systems. The impact of aerosol on storm strength was found to be very sensitive to the environment in which the storm forms. In a dry, less stable, midlatitude continental case, increasing aerosol concentration does not change the overall storm process; it does, however, slightly increase the total rainfall. The stratiform rain portion of convective systems increases consistently with increasing aerosol concentrations. In a wet, more-stable tropical maritime case, increasing the environmental aerosol concentration significantly alters the storm structure. These model simulations suggest the crucial role that aerosols might play in global hydrological cycles. Study of the climatological impact of increasing anthropogenic aerosols is also underway.

Description of Research

Aerosols pose the biggest uncertainty to the future climate according to International Commission on Clouds and Precipitation (ICCP) reports, due to the complexity of their chemical components and physical characteristics, and their short life span in the atmosphere. Quantification of the direct effect of anthropogenic aerosols, *i.e.*, the radiative forcing of the aerosol itself, has shown significant progress by using global circulation models. However, the indirect effect of aerosols, *i.e.*, changes of cloud life span and precipitation strength by increasing anthropogenic aerosols, is much harder to quantify, either by observation or by simulation. Current global models cannot explicitly resolve cloud scale variations. This greatly limits their utility in studies of aerosol indirect effects. A cloud-resolving model with explicit bin microphysical schemes, such as the newly incorporated GCE model, is capable of simulating the indirect effect of aerosol on both radiative and dynamical properties of different clouds and precipitation systems. The GEST investigator's current research focuses on the impact of aerosol concentration on mesoscale convective systems, which are responsible for most of the rainfall in the Tropics and summertime midlatitude regions.

Accomplishments during the Reporting Period

A bin spectral microphysics scheme has been combined with a 2-D version of the GCE model. Because of rapid increases in computational power, bin spectral models have become the most advanced tool to study cloud and precipitation microphysics in the realistic dynamical frame provided by GCE model. The GEST investigator has been involved in testing and developing the GCE bin spectral model. Two major improvements were implemented in the bin spectral model during the past year: One is the addition of a detailed melting procedure, which accounts for partially melted ice particles and water shedding, which allows for a more realistic diabatic heating due to melting, and a better representation of the particle's electromagnetic properties. The second improvement is the incorporation of a detailed collisional breakup scheme that allows for better replication of raindrop size distribution and the intensity of rain evaporative cooling. The 2-D bin spectral model and bulk scheme model were compared using the same initialization profile in simulations of mesoscale convective systems in both the Tropics and at midlatitudes locations. A detailed comparison of the bulk model, the bin model, and observations in a Preliminary Regional Experiment for Storm-scale Operational and Research Meteorology (PRE-STROM) case has been carried out. Raindrop size distributions, observed using surface disdrometer and *in situ* airplane-based measurements during the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) have been obtained to validate the simulated raindrop size distribution using the explicit bin model. The explicit simulation of radar reflectivity pattern and Z-R relationships and comparisons between model values and observations were presented at the *31st Radar Meteorology Conference*.

The impact of aerosol concentration on storm dynamics was reported at the Tropical Rainfall Measuring Mission (TRMM) science meeting and is in preparation for publication in a special issue of the *Journal of Geophysical Research* on the atmospheric aerosol studies. The most significant impact of aerosol on storm dynamics occurs in tropical maritime environment. Clean maritime air produces a rain system that is very weak, and little ice forms in the system. At a quasisteady state of the simulation, the majority of the rain falls from cumulus congestus that generally grows below 7 km. Dirty maritime air, on the other hand, produces a much stronger rain system that generates a significant amount of ice. The top of the storm usually reaches above 10 km. There is significantly more surface rainfall and larger anvil clouds in the dirty air scenario

Objectives for the Coming Year

In the coming FY, the GEST investigator will continue to work on simulations of different cloud/precipitation systems. The bin spectral model will be expanded to include 3-D simulations and long-time, environmentally forced cloud systems—such as stratocumulus—over the tropical ocean. Further improvements in both bin and bulk microphysics schemes in the GCE model will be made to better replicate observations, especially from satellites and radar. More recent

case studies, for example, the Cirrus Regional Study of Tropical Anvils and Cirrus Layers (CRYSTAL) cases observed in 2002, will be used to validate bin spectral model simulations and to study the detailed dynamics of sea-breeze convection in Florida. The radiative transfer scheme in the GCE model will be modified to better simulate the indirect radiative forcing of anthropogenic aerosols. Other work will be to implement another bin spectral model into the GCE model that takes into account different chemical compositions in atmospheric aerosols and their effect on cloud condensation nuclei formation.

Task 912-29-152: **Development of the Second-Generation Goddard Cumulus Ensemble Model**

GEST Investigator: Xiping Zeng

Collaborators: Wei-Kuo Tao (PI, GSFC), Joanne Simpson (GSFC)

Abstract

A cloud-resolving model with a domain size of 10^3 km can explicitly represent both clouds and synoptic large-scale circulations, and will become a useful tool in exploring the roles of clouds in weather and climate change. The Goddard Cumulus Ensemble (GCE) model is one of the best cloud-resolving models in the world. It has been widely applied to studying precipitation processes associated with convective systems from different geographic locations. This model is being upgraded to its second generation for better performance, especially in future exploration of the roles of clouds in weather and climate change. As the first step, the "exact" representation of moist thermodynamics has been explored, with moist entropy as a prognostic thermodynamic variable. Future work will address the connection of moist thermodynamics to atmospheric dynamics and cloud microphysics in cloud-resolving modeling.

Description of Research

Clouds play a central role in weather and climate change. They connect atmospheric aerosol, radiation, and circulations to each other. Due to the scale difference of aerosols, clouds, and synoptic large-scale circulations, numerical simulation is important in exploring the nonlinear relations between clouds and other factors. Thus, an important topic is how to represent clouds properly in the numerical simulation. Current numerical weather and climate models use large spatial grid size, and represent clouds implicitly with cumulus parameterization. However, the cumulus parameterization is far from satisfactory, especially in the Tropics.

In contrast to the numerical weather and climate models, cloud-resolving models use fine spatial resolution so that they can represent clouds explicitly, avoiding the cumulus parameterization. With the aid of massive parallel computation, the domain size of such models can be expanded to thousands of kilometers. Since they represent clouds explicitly and introduce cloud microphysics properly with parameterization, they provide an ideal framework to study the interactions between clouds and other factors (*e.g.,* aerosols, radiation, and synoptic large-scale circulations).

Accomplishments during the Reporting Period

Current cloud-resolving models usually use domain sizes on the order of 10^1-10^2 km, and cannot accommodate synoptic large-scale circulations. With the aid of massive parallel computation, models will be able to expand their domain sizes to 10^3-10^4 km for explicit representation of clouds and large-scale circulations. In response to this computational development, over the past year the three-dimensional GCE model was improved for implementation on massively parallel computation architectures, in cooperation with the scientists in NOAA and NASA. The parallel computation code was tested successfully, and its introduction is ready for publication.

Due to the complexity of cloud microphysics, a key consideration is how to represent moist

thermodynamics properly in cloud-resolving models for long-term (*e.g.,* months) integrations. To minimize computational errors, return to the primitive form of moist thermodynamics is proposed, in which prediction is made in terms of conservative properties such as mass and entropy. In other words, moist entropy is used as a prognostic variable in cloud-resolving modeling, and other thermodynamic variables (*e.g.,* temperature) are diagnosed from that and other prognostic variables. Previous work on warm-cloud modeling has shown the possibilities and advantages of this approach. During the past year, theoretical work on moist thermodynamics was done, providing a theoretical base for the use of moist entropy as a prognostic variable in modeling cold clouds.

Objectives for the Coming Year

In the coming year, the work on moist thermodynamics will continue with the scientists at GSFC, focusing on the connection of moist thermodynamics to atmospheric dynamics and cloud microphysics. The code package for moist thermodynamics will be developed for the second generation of the GCE model.

NASA Grant: **Organization, Structure, and Evolution of Tropical Convection and Their Environment (CV525890)**

GEST Investigator: Jian-Jian Wang

Collaborators: Robert Adler (PI, GSFC), Lawrence Carey (Texas A&M University), Song Yang (GMU)

Abstract

The primary goal of this study is to develop a physically consistent understanding of the organization, structure, and evolution of mesoscale convective systems occurring during the onset and mature phases of the South China Sea (SCS) summer monsoon. This study used Doppler radar, satellite, rawinsonde, and rain gauge data collected in May-June 1998 during the South China Sea Monsoon Experiment (SCSMEX), a Tropical Rainfall Measuring Mission (TRMM) field campaign. The SCSMEX is especially important for validating TRMM data in that it provides observations from surface-based instruments to the TRMM satellite over the SCS, an open oceanic region with importance to the global atmospheric energy and hydrologic cycle.

Description of Research

The research performed under this task is comprised of two research efforts. The first is to define the initiation, structure, and dynamics of precipitation processes associated with the onset of the monsoon; the second is to obtain quantitative vertical motion over a tropical oceanic site. This involves determining the effects of environmental conditions on the initiation, organization, evolution, and propagation of monsoon convection; documenting rainfall characteristics and the kinematic structure of monsoon convection; and characterizing the nature of precipitation transition from convective to stratiform.

Accomplishments during the Reporting Period

The research in the reporting year focused on monsoon convection associated with the mesoscale vortex that drifted eastward—along with the southern branch of westerlies around the Tibet Plateau—during the late onset stage of the South East Asian Monsoon (SEAM). Dual-Doppler and dual-polarimetric radar analysis techniques were combined for the first time to investigate the development and structure of a vigorous squall line system. The focus of this study was to document the similarities and differences in this squall line system, which occurring in the SCS summer monsoon season, using data from earlier studies on tropical and subtropical squall lines.

On 24 May 1998, the onset of the SCS summer monsoon was near its completion with the establishment of southwesterly flow at low atmospheric levels and northeasterly winds at upper levels over the SCS region. Compared to the

tropical and subtropical oceanic squall lines documented in the literature, the squall lines studied here showed significant departures from the archetypal conceptual model. Characterized by intense convection with maximum radar reflectivity about 55 dBz, the squall lines had little stratiform precipitation. The stratiform rain coverage accounted for only 10-15% of total rain area, compared to an overall 63-70% of stratiform occurrence during four TRMM field experiments in the tropics. The dominance of the convective echo was likely related to environmental conditions, as the troposphere was very dry at mid- to upper-levels and characterized by weak upper-level winds. The moistening at midlevels shown in soundings taken after the passage of the first squall line suggested that the hydrometeors carried aloft by the updrafts likely evaporated quickly in the dry environment before forming a considerable area of stratiform rain. Meanwhile, the weak environmental winds at the upper levels also limited the extension of the possible stratiform rain by failing to advect the hydrometeors away from the convective part.

Differences in the kinematic structure of the squall lines in this study, as compared to other tropical and subtropical squall lines documented in previous studies, may play an important role in deciding the stratiform precipitation mode. In a typical tropical oceanic squall line, strong low-level convergence and updrafts are found in a narrow zone close to the leading edge, where the inflow interacts with the cold pool resulting from evaporative cooling. As a result, new cells form ahead of the old ones. Low-level updrafts then move upward to the rear portion of the system and form stratiform rain. A large downdraft area is often observed behind the convective core. However, for the case of 24 May, the low-level convergence and updrafts were located in a wider area at the rear of the system, and new cells formed *behind* the old ones. Updrafts turned forward like a return flow at the mid-to-upper levels, and brought hydrometeors ahead of the convective core. Weak downdrafts ahead of the updrafts were also found.

The rain and hydrometeor characteristics of the squall line were also examined. The height and magnitude of the differential reflectivity were low compared to the other analyses on tropical mesoscale convective systems (MCS). During the early stage of SCS summer monsoon, the low-level convergence and updrafts were relatively weak and unable to lift the hydrometeors to a higher level, *e.g.,* to the mixed-phase level. In a mature cell with weak low-level updrafts and downdrafts, differential reflectivity and rain water content maxima were collocated. From a statistical point of view, precipitation characteristics in the present case over the SCS monsoon region during SCSMEX were similar to the westerly regime over the Amazon monsoon region observed during the TRMM-Large-Scale Biosphere Atmosphere Experiment in the Amazon (LBA) experiment. However, higher rain rates and rainwater contents, larger raindrops, and significantly higher ice water content between 5 km and 8 km defined the precipitation over the Amazon during the easterly regime of the TRMM-LBA.

In addition to the observational work on SCSMEX, collaborative work is underway with Dr. S. Yang latent heat profile estimation.

Objectives for the Coming Year

In the coming year, the main effort will shift to evaluating dual-polarimetric radar data collected by the new NASA Polarimetric Radar (NPOL). NPOL is currently deployed at Wallops Island, Virginia along the mid-Atlantic coast. Key technical and scientific issues to be developed and studied include standardizing procedures and methodologies to process and analyze the polarimetric radar data; examining the vertical profiles of radar reflectivity for both convective and stratiform regions; determining the rain rate in different precipitation systems; characterizing hydrometeor types and amounts in precipitation systems; comparing rain rates and drop diameters derived from polarimetric radar with observations from rain gauges and disdrometers; and comparing the results of statistical analysis of vertical structure and rainfall characteristics obtained from NPOL radar and satellite observations.

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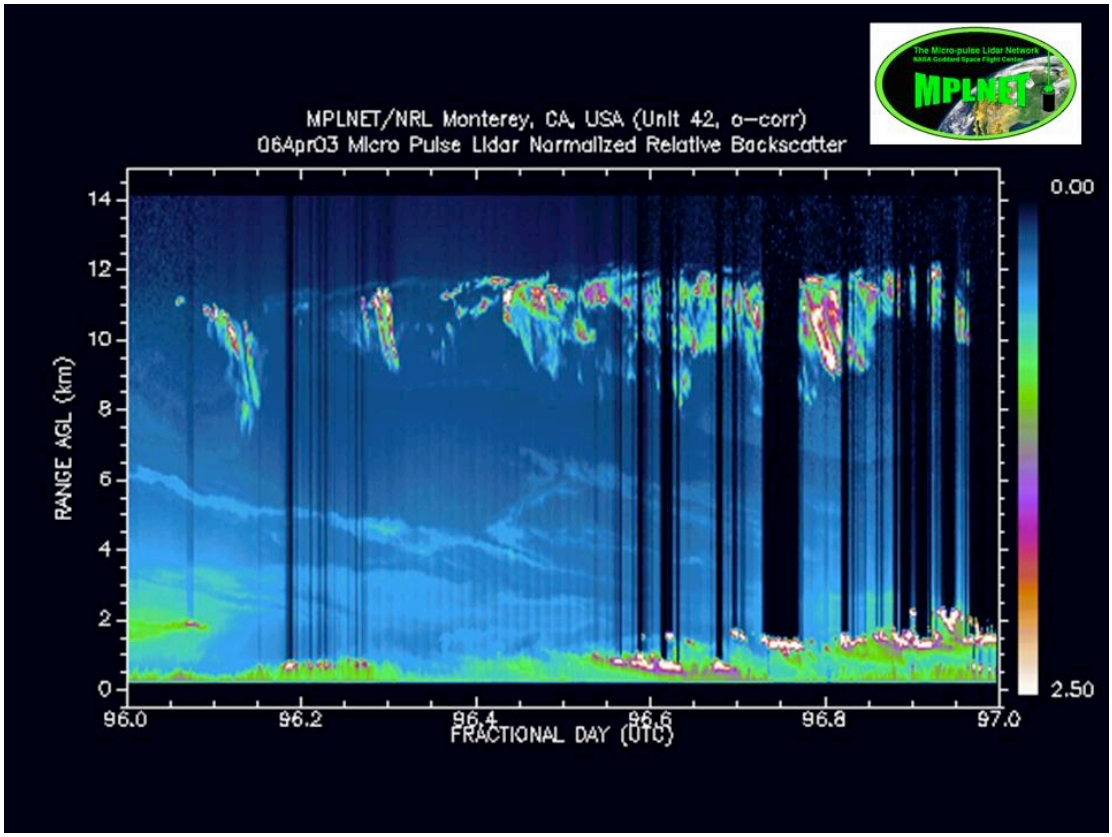
Cloud Analysis Research Group



Normalized relative backscatter (MRB) image obtained from lidar measurements at the Micro-Pulse Lidar Network (MPLNET) site in Monterey, CA on 6 April 2003. This image shows the temporal variations in the vertical distribution off a complex combination of cloud and aerosol properties. Color intensity represents the laser backscatter signal amplitude; the Y-axis is the altitude above ground level (AGL); and the X-axis is time in fractional day (UTC). Cirrus clouds can be seen in the 10-12-km range; elevated particle layers from 3-6 km; and boundary layer and low-altitude cloud dynamics in the lowest 2 km of the image. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. These types of observations are required for several NASA satellite validation programs, and have contributed to studies of dust, biomass, marine and continental aerosol properties, the effects of soot on cloud formation, and aerosol transport processes. More information about MPLNET can be found at mplnet.gsfc.nasa.gov.

Figure provided by Timothy Berkoff

Cloud Analysis Research Group

Research in the GEST Cloud Analysis Group centers mainly on analyzing data collected from various instrument sources in different areas of remote sensing. These range from microwave to lidar to other electro-optical sensors that can be ground-based, aircraft-mounted, or spaceborne. Seven faculty members are involved in the collection and analysis of data. The remaining three are involved in modeling efforts to determine climatic impacts from factors such as atmospheric aerosols.

Tim Berkoff's work with the Micro-Pulse Lidar (MPL) Network has produced a new version of the instrumentation to measure aerosols and cloud vertical distribution. It was used in the Naval Research Laboratory's Asian Dust Above Monterey (ADAM) field study in April 2003. Other MPL instruments were deployed for field campaigns, and supporting technical work was provided to locations that ranged in location from the local Clouds and the Earth's Radiant Energy System (CERES) Ocean Validation Experiment (COVE) platform in the Chesapeake Bay and the Small and Moderate Aperture Research Telescope System (SMARTS) trailer at GSFC, to the Amundsen-Scott South Pole Station, and another in Norway.

Reginald Lancaster used data from the large-format, uncooled, infrared (IR) detector arrays collected during a Shuttle flight of an Infrared Spectral Imaging Radiometer to study stereo capabilities in electro-optical instrumentation development. His work also supports the Geoscience Laser Altimeter System (GLAS) payload from ICESat through work in improvements of solar filtering.

The effect of thin cirrus clouds on IR sensors' retrievals of water vapor formed the basis of Zhien Wang's work, which is directed at improving observations of the atmospheric moisture field from Advanced Infrared Sounder (AIRS) and Goddard Earth Observing System (GEOS). He is also developing algorithms for two future CloudSat products: radar only, and combined lidar-radar cloud scenario classifications. In yet another area of research, Dr. Wang develops new ground-based algorithms for mixed-phase cloud and cloud-type studies using Atmospheric Radiation Measurement (ARM) Clouds and Radiation Testbed (CART) site observations. The thrust of these research efforts is to improve our understanding of cloud radiative feedback and the global atmospheric water cycle.

Ashwin Mahesh also used GLAS measurement data in combination with overlapping Terra and Aqua satellite observations to develop comparative techniques for atmospheric profiling. Dr. Mahesh also studies polar areas, looking at ice clouds and blowing snow at South Pole station to develop a "standard" atmosphere for Antarctica. Data for this standardization were presented at the *Seventh Conference on Polar Meteorology.*

Besides Dr. Mahesh's work on multiple scattering effects on lidar observations, Igor Veselovskii also addressed the problem of lidar scattering by melting hydrometeors, by analyzing the scattering properties of eccentric spheres. He extended the Mie backscattering model for off-centre inclusion, and considered water particles of various ice-water compositions to seek insight into the lidar bright and dark band formation.

Microwave-based observations were the focus of research by both Liang Liao and Kevin Horgan. Dr. Liao's work is on dual-wavelength polarimetric radar measurements of stratiform and convective rain; these can be extended to snow observations. His studies using airborne and ground-based radar data will likely be applied to space-based microwave radar measurements of hydrometeor profiles. He will continue his work with the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar.

Kevin Horgan is working to develop an advanced space-borne radiometer to measure sea surface salinity. This research is a precursor to the upcoming Aquarius mission, using radio frequency (RF)-powered detectors in a prototype radiometer to improve models used to mitigate their nonlinear response. Further tests of the Microwave Integrated Circuit (MIC) polarimetric radiometer will take place in the framework of a cryogenic testbed to simulate the effects expected in a space environment.

Guoyong Wen is studying both total and spectral solar irradiance using Solar-Stellar Irradiance Comparison Experiment (SOLSTICE) data from the Upper Atmosphere Research Satellite (UARS) satellite, Aerosol Robotic Network (AERONET) sunphotometer measurements, and SORCE data. This research focuses on solar radiative transfer under clear-sky and atmospheric turbidity conditions, to establish the atmospheric effects on solar spectral irradiance transport. The observational database will be extended to observations from Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal and Emissions Radiometer (ASTER), and Multiangle Imaging Scanning Radiometer (MISR) to include different spatial resolutions and angular capabilities.

Finally, Fanglin Yang's research focuses on climate modeling and diagnosis, using atmospheric and oceanic general circulation models (GCM) as the principle tool, supplemented by statistical methods and low-dimensional numerical models. He has developed a 30-layer mixed-layer ocean (MLO) model, and coupled it to the finite-volume General Circulation Model (fvGCM) to study the impact of aerosols on climate. In particular, he has investigated the impact of sea surface temperature (SST)s and aerosols on East Asian precipitation trends and variability.

In summary, the group's common theme is the use of observations and analysis of data acquired from a number of remote sensing technologies and sources to further our understanding of the physical Earth and to improve our abilities to collect such data.

Tom B. Low (Acting)

Task 912-01-012: **Development of Advanced Electro-Optic Instrumentation and Technologies for Earth and Climate Monitoring**

GEST Investigator: Reginald S. Lancaster

Collaborator: James D. Spinhirne (PI, GSFC)

Abstract
This research activity advances the capabilities of electro-optic instrumentation and technologies used in satellite remote sensing. These instruments include visible and infrared imaging radiometers and critical component technologies for daytime atmospheric lidar systems. The imaging radiometer development effort is designed to provide low-cost infrared and visible imagery for small space missions that passively sense cloud, land, and ocean properties. The goals driving component development for atmospheric lidar are similarly to increase the reliability and robustness of space-based systems, thereby enabling new and more aggressive measurement capabilities.

Description of Research
Developing advanced electro-optic instrumentation is critical to the future of atmospheric studies. Among the complement of instruments used in satellite remote sensing missions dedicated to Earth and climate monitoring is the thermal infrared imaging radiometer. Associated with such instruments has been the cost and complexity of actively cooling the infrared detectors used as image sensors. However, with advances in detector technologies thermal imaging radiometers can now be built that are free from the constraints imposed by these cooling requirements. The resulting payloads are compact, power-efficient, and less costly to develop. Current research includes developing different infrared and visible imaging radiometers for advancement to potential missions of opportunity within the Earth Science System Pathfinder (ESSP), New Millennium, and Global Precipitation Mapping programs.

Advances in lidar technologies have consistently enabled Earth science missions to assume increasingly challenging measurements goals. The Ice, Cloud, and land Elevation Satellite (ICESat) represents a major advance in space lidar technology. It was the first to directly measure the heights of clouds and aerosols from a robotic orbiting platform. Placed into polar orbit in January 2003 as part of NASA's Earth Observing System (EOS) program, the ICESat mission carried as its sole payload the Geoscience Laser Altimeter System (GLAS). A major component of work performed under this task was to develop a unique, thermally tuned solar filter used to enable daytime measurements with this satellite payload.

Accomplishments During the Reporting Period
The unique stereo capabilities accompanying the use of large format infrared detector arrays were explored. These capabilities were examined using data from the Shuttle-based flight of the Infrared Spectral Imaging Radiometer (ISIR) instrument, which was the first space-based radiometer to utilize an uncooled detector array for Earth science monitoring. The design specifications of this instrument were expanded upon by performing an engineering study for an upcoming ESSP opportunity, using multiple camera systems to achieve wide-field measurements to monitor water vapor. A laboratory breadboard instrument appropriate for these opportunities was designed and tested. ICESat was successfully launched from Vandenberg Air Force Base in January 2003. Research activities were then conducted to understand and characterize the performance of the solar filter subsystem on orbit; the subsystem worked extremely well.

Objectives for the Coming Year
Design and development of the infrared and visible imaging radiometers will continue, with emphasis on meeting the mission goals of various large and small space programs—including those mentioned previously, and the possibility of other, smaller missions of opportunity and on unmanned aerial vehicles. Future space missions using lidar remote sensing will likely be even more aggressive in their intent, and further technological

advances are therefore imperative. In the case of atmospheric lidar, these advances can be measured in terms of increasing sensitivity to the faint return signals typical of probing an optically thin target such as the atmosphere. This challenge must be addressed, in part, through spectral filtering, without which a diurnal variation is necessarily introduced into the measurement precision. Research activities will be directed toward advancing the capabilities of the solar filters beyond what was used with the GLAS payload, and for use with the next generation of space lidar systems.

Task 912-06-088: **Space-Borne Lidar Studies of Polar Clouds and Climate**

GEST Investigator: Ashwin Mahesh

Collaborator: James Spinhirne (PI, GSFC)

Abstract

The Geoscience Laser Altimeter System (GLAS) was launched on board the Ice, Cloud, and Land Elevation Satellite (ICESat) in January 2003. GLAS is the first spaceborne laser. Active atmospheric profiles from this system became available in early 2003 for a five-week period, and again in the fall and winter. Combining GLAS data with those from other observing efforts—passive sensors, ground-based observations, radiosondes, etc.—allows significant new gains to be made in our understanding of high-latitude climate phenomena. For example, GLAS measurements have for the first time made it possible to validate passive observations of the atmosphere using physical interactions between photons and atmospheric layers. Laser observations in the high latitudes have also significantly reduced ambiguities in detecting ice clouds, and significantly increases the potential to create climatologies of high-latitude clouds. The availability of the new observing method has also made it possible to study local phenomena specific to the poles, especially in Antarctica, *e.g.,* blowing snow at the surface, and polar stratospheric clouds. These observations are complementary to ongoing theoretical efforts to understand polar clouds and their impact on regional and global climates.

Description of Research

The broad purpose of these studies is to characterize polar clouds and climate more accurately for inclusion in general circulation models (GCMs), and to determine the impacts of clouds, snow, and ice particles on the radiation balance between the surface and the atmosphere in the high latitudes.

Photons from a laser traveling through the atmosphere interact with cloud and aerosol particles; the nature of this interaction can be deduced from observations of the photons that are returned to the receiver on the satellite. This is a key improvement over historical passive imaging technologies: Because clouds and snow look very similar from space (both in the infrared and at visible wavelengths), passive images often cannot distinguish the two, and GLAS's unambiguous detection is a significant improvement in space-based detection and analysis. In other, related work, the layering of Antarctic clouds, their frequency of occurrence, and their typical thickness are being studied to develop a complete climatology of clouds over the entire high plateau. Climate modelers have used standard atmospheres since the late 1970s to represent various climate regions in their models; an Antarctic profile, however, does not exist. However, multidecadal ground-based observations of the Antarctic atmosphere are available for study, along with GLAS and other satellite-based observations. These can be used to compile a "standard" atmosphere of the Antarctic. Other work under this task calls for defining standard profiles to represent the Antarctic atmosphere, as such profiles are vital to estimating and understanding changes in regional and global weather expected over the next few decades. The satellite- and ground-based measurements provide the means to broadly characterize the Antarctic atmosphere; in addition, it is necessary to understand the

microphysical and radiative properties of atmospheric layers. A climatology of blowing snow over the high plateau has been developed from surface-based spectral and laser observations. Polar stratospheric clouds are also being studied using the same instruments. The spectral data were used to test a new algorithm to improve the determination of large cirrus cloud particle sizes.

Accomplishments during the Reporting Period

GLAS observations from February and March 2003 provided the first opportunity to validate passive measurements from other satellites using the actively profiled atmospheres from ICESat. Using overlapping flights of GLAS and the Earth Observing System (EOS) Terra and Aqua satellites, a subset of data was selected for preliminary study. A comparison between scene identification algorithms used with Aqua spectral data and a threshold technique used to detect cloud layers in GLAS observations agrees more than 75% of the time over a large range of latitudes. Disagreement is higher in nighttime than in daytime observations, and also over snow-covered latitudes in the northern hemisphere. Similar conclusions can also be drawn from coincidences between ICESat and Terra data, but there are significant disagreements in the high latitudes. These comparisons illustrate the potential for active atmospheric profiling to validate techniques used with passive observations [Mahesh *et al.* 2004].

Spectral observations of cirrus clouds can be analyzed to obtain cloud particle effective radii using measurements at selected wavenumbers in the infrared atmospheric window. The suitability of these wavenumbers to determine a range of sizes is constrained by the dependence on particle radius of ice absorption efficiency (Q). By using only those wavenumbers at which Q varies monotonically with radius, cloud particle radii up to approximately 20 μm can be determined; larger values, however, present problems. At some wavenumbers, the variation in Q is not sufficiently large to distinguish between large particle radii. At other wavenumbers, larger particles are more easily distinguished, but Q_{abs} values do not correspond to unique particle radii. The limitations faced at individual wavenumbers can be partially overcome by using only one set of wavenumbers to determine whether the particle is large or small, and a second set to actually determine the effective radius of a large cloud particle. This was demonstrated using yearlong spectral observations of ice clouds at the South Pole Station [Mahesh 2004].

Observations of blowing snow made by surface observers at the South Pole Station were analyzed using data from the 1990s. A climatology developed from these observations showed blowing snow to be present roughly a third of the time. Typical wind velocities and directions during blowing snow events were also noted. Laser-based observations of near-surface atmospheres were also carefully screened to find blowing snow cases, and typical heights of such layers were determined. The radiative effect of blowing snow was quantified using spectral data: The energy balance at the surface of Antarctica is affected by blowing snow in a manner comparable to that cause by thin clouds [Mahesh *et al.* 2003a].

Significant progress was made in developing a "standard" atmosphere of Antarctica. The key features of climate over the continent—strong temperature inversions, high emissivity surfaces, the relative absence of water vapor, significant variation in ozone concentrations, etc.—were gathered into standard seasonal profiles. The data for such standardization included both satellite observations of the upper atmosphere and many ground-based records [Mahesh *et al.* 2003c].

Algorithms developed to quantify multiple scattering effects on GLAS observations as part of the preparatory science for the ICESat mission were put to use, and the impact of multiple scattering on laser observations was confirmed. Procedures to correct observations for the impact of multiple scattering have been developed, and will be used with the data before it is made available for studies by other researchers.

Objectives for the Coming Year

A climatology of polar clouds will be developed from GLAS observations. This will be compared to earlier studies of Antarctic clouds using ground-based observations [Mahesh *et al.* 2001a, 2001b]. A standard atmosphere of the Antarctic plateau will be established and made available to global

climate modelers; separate profiles may be created to represent different phases of the climate of the high plateau (spring, summer, and winter). Simultaneous spectral and lidar observations of polar stratospheric clouds will be analyzed to determine their frequency of occurrence and radiative effects. Similar observations will also be used to study the accuracy of techniques to determine cloud boundaries from spectral data. Further validation of passive observations using GLAS data will be initiated. Multiple scattering effects on GLAS observations will be corrected, and GLAS atmospheric data made available for use by other researchers.

Task 912-31-157: **Analysis of Scattering Properties of Eccentric Spheres in Application to Lidar Measurements**

GEST Investigator: Igor Veselovskii

Collaborator: David N. Whiteman (PI, GSFC)

Abstract

A Mie backscattering model for spherical particles with off-centre inclusion has been developed and tested. The program is capable of dealing with size parameter values up to approximately 1000, thus allowing the simulation of the optical behaviour of a large variety of atmospheric aerosols, as well as cloud and precipitation particles. Based on this model, simulations were generated of the optical properties of polydisperse composite atmospheric particles as observed by ground-based and airborne lidar systems. Optical properties have been characterized in terms of host and inclusion radii, considering water particles with different composition inclusions. The performed modeling provides some insight into the so-called lidar bright and dark band phenomenon.

Description of Research

One of the topics actively being studied with the use of radars and lidars is the change in scattering properties of melting hydrometeors. Such changes take place during the snowflake-to-raindrop transition in proximity to the freezing level, leading to a minimum in particle backscatter at optical wavelengths. Although not quite exact, melting hydrometeors are frequently modeled as a two-layered particle, consisting of a water shell about an inner core of snow or ice. The eccentric spheres model may represent an approximation for such two-layered particle: The core can float to the top of the water drop due to entrapped air bubbles. The first attempt to simulate the melting of ice particles with the use of Mie code for eccentric spheres and its application to the dark and bright band phenomenon was made by Di Girolamo *et al.* [2004]. The authors used a scattering code, which could perform calculations for monodisperse particles with size parameters up to approximately 100. The results demonstrated the importance of eccentric model implementation, but the large computation time did not allow consideration of polydisperse aerosols of sufficient size to draw conclusions about the changes of scattering properties that may occur in real atmospheres. The result of this research is the development of an eccentric model capable of handling size parameter values as large as 1000. The model was applied to study the changes in scattering properties of melting ice spheres, getting some insight into the so-called lidar bright- and dark-band phenomenon.

Accomplishments during the Reporting Period

Existing algorithms to compute light scattering by spheres with nonconcentric spherical inclusions are based on a recurrence approach to calculate the scalar and vector coefficients for the translation of vector spherical harmonics from one coordinate system, adjusted to the center of inclusion particle, to another, adjusted to the host center. Although these methods allow the calculation at any scattering angle for arbitrary position of inclusion inside the host sphere, the computation time increases quickly with increase in particle radius. To simplify the formulas and thus decrease the computation time, several qualifications were instituted: only light backscattering—relevant in lidar measurements—was considered; and the movement of the inclusion was limited to the axis

of the direction of incident light propagation. Such simplifications should be reasonable, for example, in the case of nuclear ice floating in a water droplet, and considering only vertical lidar measurements.

The main focus of this work is to understand the scattering properties of combined hydrometeors, consisting of spherical host and a spherical inclusion, and how these may be revealed in lidar experiments. The main questions addressed in this study are how the particle scattering properties depend on inclusion size, its location inside the host, and their respective refractive indices. The question is further simplified by assuming that the refractive index of the host in our calculations corresponds to pure water at 355 nm, while refractive index of the inclusion may be higher or lower. The special case of interest here is a water droplet with an ice inclusion.

Two of the geometries that have been considered cover the relative size of the ice and water mass, and the location of the ice inclusion within the water drop. The refractive index of ice is lower than that of water, and, just as was found earlier, maximum backscattering is observed for an inclusion located near the bottom of the water sphere. Under these conditions, approximately a 50-fold enhancement in backscattering is observed, limited to a narrow region of relative radius. For the case of the inclusion located near the top of the host, the backscattering is characterized by an oscillating trend with smaller enhancements. The results may be summarized as follows: Specific inclusions strongly increase backscattering when located near host particle bottom, and at specific relative inclusion radii. For some cases, the backscattering enhancement is observed for the top inclusion location; similarly enhancement is observed for an eccentric inclusion location, while in the concentric geometry the backscattering increase is much smaller. The particle extinction doesn't depend significantly on inclusion position, so the rise of backscattering should be accompanied by decreasing lidar ratio. Interestingly, it appears that the lidar ratios should be different when measuring from aircraft and from the ground.

The computer code that was developed was applied to simulating the scattering properties of melting ice spheres, in an attempt to understand lidar bright and dark band phenomena. The results demonstrate that the shift of ice nuclei along the Z-axis leads to the strong variations in the light backscattering coefficient and, in principle, may be responsible for the experimentally observed scattering enhancement. The model is idealized as an approximation of the real situation: the deformation of water droplet and possible movement of inclusions inside the drop due to drag-induced internal circulations are ignored. Ice nuclei are assumed for simplicity to be spherical, while in reality their shapes are complex. Nevertheless, there is a resemblance between the results of experimental measurements and these simulations, which demonstrate the importance of an eccentric nuclear position in the elucidating the mechanism of lidar bright and dark band formation.

Objectives for the Coming Year

Development of algorithms for retrieval of aerosol and clouds properties from the laser light backscatter will continue. One short-term goal is to investigate the limits of the multiwavelength lidar technique. The use of multiwavelength Raman lidar techniques in combination with sophisticated inversion algorithms has been recognized as a new tool to derive information about microphysical properties of atmospheric aerosols. The optical input parameter sets, provided by respective aerosol Raman lidars, are at the theoretical lower limit at which these inversion algorithms work properly. For that reason there is ongoing intense discussion on the accuracy of the inversion methods used for the retrieval of the microphysical parameters, and the possibility of the simultaneous retrieval of the particle size distribution and the complex refractive index. An eigenvalue analysis to study the information content of multiwavelength lidar data is planned. Such an analysis should provide a firm mathematical basis for insight into the limitations of these inversion algorithms, and will allow determination of the range of particle microphysical parameters within which the complex refractive index can be derived with sufficient accuracy, and to estimate corresponding uncertainties.

Task 912-52-202: **The Micro-Pulse Lidar World-wide Observational Network**

GEST Investigator: Timothy Berkoff

Collaborators: Judd Welton (PI, GSFC), James Campbell (SSAI), James Spinhirne (GSFC), Brent Holben (GSFC), Si-Chee Tsay (GSFC), Stan Scott (GSFC)

Abstract

Accomplishments this year include the commercialization of a new version of the Micro-Pulse Lidar (MPL) instrument in the Micro-Pulse Lidar Network (MPLNET), investigation of thermally induced MPL overlap calibration bias errors, and construction of the Small Lidar Advanced Measurement (SLAM) facility. Engineering improvements were applied to a number of lidar systems in the network. As a result, the MPLNET project benefited from improved network operations and the continuation of enhanced instrumentation capabilities.

Description of Research

The MPLNET is comprised of lidars stationed around the globe to provide measurements of aerosol and cloud vertical distributions on a continuous basis. Reliable and accurate instrumentation performance in the field is essential to assure the generation of high-quality data from remote sites. Investigation of technology issues in relation to network operational activities is a key component in the success of MPLNET. Each lidar installation in the network consists of a telescope, laser, receiver optics, detector, and a data collection system. These lidar systems are novel in that they are portable and eye-safe, and therefore present a unique set of technology challenges different from traditional lidar systems. Investigations are focused primarily on improving instrument optical stability, developing new measurement techniques to monitor and maintain data quality in the field, and commercializing a new instrument tailored to MPLNET. This work is accomplished through analytical and numerical analysis of instrument characteristics to address known measurement and operational issues. Engineering upgrades and improvements are first demonstrated at the prototype level in the laboratory, and then applied to MPLNET instruments to be deployed into the field.

Accomplishments during the Reporting Period

During this reporting period, a new version of the MPL—called "Type 4"—was operated successfully in the field for a period of three months; it provided data during the Naval Research Laboratory (NRL)'s Asian Dust Above Monterey (ADAM) field campaign in April 2003. Unlike prior MPL systems, this new instrument is tailored specifically to the latest MPLNET operational requirements, and incorporates a number of important changes. Results obtained from this system demonstrated a significant improvement in daytime signal-to-noise performance over prior MPLs. In order to facilitate commercialization of the Type 4 MPL, component and subassembly information and system specifications were used to define a GSFC contract to procure three replicas of the Type 4 prototype through a commercial vendor. This contract was successfully awarded in August 2003 to Sigma Space. Technical advice, subassembly specifications, optical alignment procedures, and assistance were provided to ensure successful delivery of the first commercial unit. Delivery of the remaining two systems to GSFC is expected in 2004; additional purchases are anticipated by research groups that have already expressed interest in joining MPLNET. As a consequence of this commercialization effort, the MPLNET network has the potential now to expand to a much larger number of participants.

The new SLAM calibration/validation facility was constructed in the MPLNET laboratory workspace. This provides a dedicated system to align and optically characterize MPLs, and includes a custom-designed nine-inch Newtonian-style collimator, a digital camera and image display, an analysis workstation, and calibrated transmission equipment. The SLAM facility is now operational, and autocollimation measurements have demonstrated the high resolution needed to more consistently and

systematically evaluate MPLs before and after field deployment. This facility will now serve as the primary calibration and validation resource for MPLNET lidars.

In other, related work, variance in the MPL overlap function was analytically studied. The determination and stability of the instrument overlap function is a critical calibration step required to process the raw signal returns from each lidar in the network. A preliminary study of the MPL overlap function indicated that a relatively simple numerical model could be used to accurately reproduce the nonlinear response of the MPL near-range overlap when compared to experimentally obtained results. This model was then modified to permit thermally induced overlap variances due to a temperature change in the instrument's operating environment. These simulations allowed estimates of range-dependent data bias error due to temperature changes, and also revealed a bias error effect on the retrieval of the MPLNET lidar constant from atmospheric data. This model also enabled development of improved specifications for a thermally stable telescope, to passively reduce bias errors in MPLNET data products.

Several MPLs were upgraded with a variety of engineering improvements, benefiting research sites and activities around the globe. This included MPL012 for deployment at the CERES Ocean Validation Experiment (COVE) platform on the Chesapeake Bay, the MPL001 installation in the Surface Measurement Atmosphere Radiative Transfer (SMART) trailer at GSFC, and deployment of MPL018 to the 2003 Aerosol Intensive Observations Period (IOP) campaign at the Department of Energy's Atmospheric Radiation Measurement (ARM) site in Oklahoma. Technical advice and support was also provided to enable the continued operation of MPL020 at the Amundsen-Scott South Pole Station, and MPL010 in Norway.

Objectives for the Coming Year

During the next reporting period, the new Type 4 system should be available for purchase by research groups interested in joining MPLNET.

This will provide a new avenue for research groups interested in long-term studies of aerosol and cloud properties to participate in MPLNET. Technology improvements in existing systems within the network will continue, and demonstration of improved techniques is expected including further developing and refining overlap correction methods, site implementation, and investigations of instrument stability.

Task 913-12-117: **NASA Seasonal-to-Interannual Prediction Project: Effects of Extra-Tropical Air-Sea Interactions on Predictability of Warm Season Precipitation Anomalies over the United States**

GEST Investigator: Hailan Wang

Collaborator: K.M. Lau (PI, GSFC)

Abstract

To better understand the impact of extratropical air-sea interactions, the newly developed GSFC Mixed Layer Ocean model (MLO) of variable depth has been coupled to the NASA Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric general circulation model (AGCM). A series of experiments was performed using the NSIPP AGCM, and the AGCM coupled to the GSFC MLO. The model outputs are being analyzed to reveal the physical and dynamical mechanisms through which extratropical air-sea interactions affect interannual climate variations during summertime in the U.S.

Description of Research

This work is an investigation into the mechanisms and the roles of extratropical air-sea interaction on the predictability of U.S. summertime precipitation anomalies using observations and NASA NSIPP models. The research focuses on the identification of boreal summer teleconnection

patterns and associated extratropical sea surface temperatures (SST) variability and how they relate to tropical SST during, *e.g.*, an El Niño/Southern Oscillation (ENSO) event. The research effort involves climate diagnosis of various physical and dynamical fields from observations and simulations of a number of coupled and uncoupled GCM experiments. The potential importance of North Pacific air-sea interactions has been indicated in statistical analyses of observations and in simulations of the type used in NSIPP Atmospheric Model Intercomparison Project (AMIP).

Accomplishments during the Reporting Period

The interannual variability of summertime rainfall over the U.S. may be linked to climate anomalies over the Pacific Ocean and East Asia through teleconnection patterns that may be components of recurring global climate modes in boreal summer [Lau and Weng 2002]. In the past year, the maintenance mechanisms of the boreal summer teleconnection patterns were investigated using observational data and NSIPP AMIP-type simulations. Statistical analysis indicates that the interannual variability of observed warm season precipitation over the U.S. is largely related to SST variation in both the tropical and North Pacific Ocean, whereas the NSIPP AMIP-simulated summertime U.S. precipitation variations mainly reflect the impact of ENSO in the tropical Pacific. Given the absence of air-sea interactions in NSIPP AMIP-type simulations, this implies the potential importance of air-sea interactions in the North Pacific in explaining the interannual variability of observed summer climate over the U.S.

The anomalous atmospheric circulation associated with the dominant summertime teleconnection modes in both observations and NSIPP AMIP simulations are diagnosed using a stationary wave modeling approach. In observations of the two dominant singular value decomposition (SVD) modes, both anomalous diabatic heating and anomalous transients significantly contribute to the anomalous circulation. The distributions of the anomalous diabatic heating and transient forcing are configured in quadrature over the North Pacific and North America, so that both forcings could act constructively to maintain the teleconnection patterns. The contrast between observations and NSIPP AMIP simulations from stationary wave modeling diagnoses confirms the previous conclusion, based on statistical analysis.

A better understanding of the impact of extratropical air-sea interactions necessitates use of the NSIPP AGCM coupled to a MLO model. Heat and salt flux adjustments for the NSIPP AGCM have been obtained, using a MLO of variable depth provided by Mike Alexander from the National Oceanic and Atmospheric Administration (NOAA)'s Climate Diagnostics Center (CDC) [Alexander *et al.* 2000], and a newly developed GSFC MLO of variable depth, provided by GEST's Fanglin Yang. Based on a comparison of SST climate biases in offline hindcast using the two MLOs, the GSFC MLO was chosen, and has been coupled to NSIPP AGCM. Using the NSIPP AGCM and an AGCM coupled to GSFC MLO, a series of long standardized experiments were performed. The experiments differ from one another in the configuration of oceanic low boundary conditions. Each of the experiments contains nine members, integrates from 1901 to 2000, and takes up to three months to complete. The outputs of the experiments are currently being analyzed. The comparison between different model simulations sheds light on the physical and dynamical mechanisms through which the air-sea interactions in the extratropics, particularly over the North Pacific Ocean, affect interannual U.S. climate variations.

Objectives for the Coming Year:

The outputs of the experiments described above, along with existing outputs of NSIPP AMIP-type experiments provided by the NSIPP group, will be further analyzed using various statistical techniques and a diagnostic stationary wave modeling approach. The interannual variation of atmospheric circulation, precipitation, SST, storm tracks, stratocumulus clouds in extratropical regions, and their interlinkages in each experiment will be examined. A better understanding of the maintenance of the summertime teleconnection that links the East Asian and U.S. climates will be achieved. The results from the above coupled model experiments will be compared to empirical benchmarks.

Task 913-12-117: **Modeling and Diagnosis of Asian Climate: Impact of SSTs and Aerosols**

GEST Investigator: Fanglin Yang

Collaborators: Williams K.M. Lau (PI, GSFC), Arun Kumar (NOAA), Michael E. Schlesinger (UIUC), Wanqui Wang (NOAA)

Abstract

This study investigates the forcing mechanisms for the trend and variability of Asian precipitation in boreal spring and summer. Research has led to improved understanding of the relationship between the trend and interannual variability of the dominant modes of East Asian monsoonal precipitation. Observational analyses and numerical model experiments were combined to explore the forcing mechanism for trends in Asian precipitation. Among the factors investigated were the warming trend in global sea-surface temperatures and the increase of black carbon emissions.

Description of Research

The research conducted under this task focuses on climate modeling and diagnosis, using atmospheric and oceanic general circulation models (GCM) as the principle tool, supplemented by statistical methods and low-dimensional numerical models. Past research covered investigations of radiative forcing and climate changes induced by volcanic aerosols and greenhouse gases, developing atmospheric GCMs, and predicting and diagnosing climate over seasonal-to-interannual time scales, forced by anomalous boundary conditions associated with SST, snow, and soil moisture. More recent research has focused on investigating the forcing mechanisms of the trend and variability of Asian monsoonal precipitation, and on developing a multilayer/ mixed-layer ocean model. In addition, the intensity of hydrological cycles in warmer climate and the predictability of U.S. summer climate associated with soil moisture anomalies have been studied.

Accomplishments during the Reporting Period

A 30-layer Mixed Layer Ocean (MLO) model was developed, based principally on mixed-layer physics and advanced numerical and computational techniques. This MLO model was coupled to the GSFC finite-volume Global Circulation Model (fvGCM) to study the impact of aerosols on climate. This approach has been adopted by members of the research community, including Hailan Wang at GSFC, who is coupling the MLO with the GMAO NASA Seasonal-to-Interannual Prediction Project (NSIPP)-1 model to study midlatitude air-sea interactions; Ming Cai, at Florida State University, is using this MLO for classroom demonstrations; David DeWitt, at the International Research Institute in New York, is applying this MLO for El Niño//Southern Oscillation (ENSO) forecasting.

The trend and variability of East Asian precipitation were explored. Observational records over the past 50 years show an upward trend in boreal summer precipitation in central-to-east China, and a downward trend in north and southeast China; during boreal spring, the trends are reversed. This suggests a dynamical response of the East Asian monsoon system to some climate forcings that have not been clearly defined. In this study, the forcing mechanism of global sea surface temperatures (SSTs) on the interannual variability and trend of East Asian monsoonal precipitation in both spring and summer were explored by first performing observational data analyses and then running GCM experiments. As part two of this study, the possible forcing mechanism of black carbon from industrial pollution and biomass burning on the decadal precipitation trend was investigated. Attention has been paid to how aerosols might have influenced large-scale atmospheric circulation and SSTs, leading to possible decadal-scale precipitation anomalies. The investigation was carried out based on sensitivity GCM experiments using the Global Modeling and Assimilation Office (GMAO) fvGCM coupled with the 30-layer MLO developed under this task.

The intensity of hydrological cycles in warm climate was investigated using numerical models. The fact that the surface and tropospheric temperatures increase with increasing CO_2 has been well documented by numerical model simulations; however, less agreement was found for changes in the intensity of precipitation and the hydrological cycle. Work performed under this task demonstrated that while both the radiative heating by increasing CO_2 and the resulting higher sea surface temperatures contribute to atmospheric warming, they act against each other in changing the hydrological cycle. As a consequence, in a warmer climate forced by increasing CO_2 the intensity of the hydrological cycle can be either more or less intense, depending upon the degree of surface warming.

The potential to predict surface air temperature and precipitation over the continental U.S. was assessed for a GCM forced by observed SSTs and estimates of ground soil moisture contents. The latter were obtained by substituting the GCM-simulated precipitation, which is used to drive the GCM's land-surface component, with observed pentad-mean precipitation at each time step of the model's integration. With this substitution, the simulated soil moisture correlates well with an independent estimate of observed soil moisture in all seasons over the whole continental U.S. Significant enhancement of the predictability of surface air temperature and precipitation was found in boreal late spring and summer over the continental U.S. continent.

Objectives for the Coming Year

The first major activity for the coming year is to complete the investigation of the trend and variability of East Asian monsoonal precipitation. The second is a new activity, which involves participation in an interdisciplinary study of cloud-radiation-precipitation modeling and assimilation to improve weather and climate modeling. Arthur Hou at the GMAO leads this project.

Task 913-48-190: **Atmospheric Solar Radiative Transfer**

GEST Investigator: Guoyong Wen

Collaborators: Robert F. Cahalan (PI, GSFC), Alexander Marshak (GSFC), Lazaros Oreopoulos (JCET), Tamás Várnai (JCET), Brent Holben (GSFC), Juan Fontenla (University of Colorado), Thomas Woods (University of Colorado)

Abstract

The research focuses on solar radiative transfer under clear atmospheric conditions, including aerosol retrievals, atmospheric correction for satellite images, and the effects of atmospheric turbidity on the estimation of exoatmospheric solar spectral irradiance from ground-based radiometers. Studies have theoretically quantified the limitation of ground-based estimates of solar spectral irradiance. Solar-Stellar Irradiance Comparison Experiment (SOLSTICE) spectral solar irradiance from the Upper Atmosphere Research Satellite (UARS), and Aerosol Robotic Network (AERONET) sun photometer measurements were used to demonstrate the theoretical limitations. The Solar Radiation and Climate Experiment (SORCE), launched in January 2003, will provide the total solar irradiances (TSI) and spectral solar irradiance (SSI) for the analyses. When combined with ground-based observations, a better understanding of clear sky atmospheric radiative transfer will result.

Description of Research

Solar radiation is the major energy source for Earth's biosphere, and it directly affects physical, chemical, and biological processes on the Earth. It is the direct forcing for atmospheric and oceanic circulations and climate. Understanding this input energy is crucial for understanding Earth-atmosphere system processes. The objective of this research is to study the atmospheric effects on solar spectral irradiance transport. In this case, the input solar spectral irradiance is from direct observations from the SORCE satellite. SORCE,

launched in January 2003, provides total solar irradiance from the Total Irradiance Monitor (TIM), UV spectral irradiance from SOLSTICE, and spectral irradiance from the Spectral Irradiance Monitor (SIM). Data from ground-based AERONET sun photometers at the Atmospheric Radiation Measurement (ARM) site provide spectral and broadband solar irradiance measurements. Satellites, such as the Earth Observing System (EOS) Terra and Aqua platforms, routinely provide reflected solar radiation at the top of the atmosphere. With satellite and ground-based solar radiation measurements, and atmosphere profiles from soundings, a new approach to examine the clear sky radiative transfer is at hand.

Accomplishments during the Reporting Period

An exploration of the theoretical limitations of ground-based estimates of solar spectral irradiance was carried out. The uncertainty in the ground-based estimates from traditional Langley plot method is analytically expressed as a function of temporal variation of the atmospheric aerosols. This provides the theoretical basis of the inadequacy of monitoring solar variation from ground-based estimates. The theoretical limitation was applied to real ground-based estimates and satellite observations to justify the theory. Even at the cleanest site (Mauna Loa, HI), the ground-based estimates from AERONET sun photometers were unable to capture solar variations as observed from SOLSTICE on UARS. Efforts were also made to measure the TSI from rocket and high-altitude balloons and aircraft in the 1960s and 1970s. The TSI at the mean Sun-Earth distance had been known as the solar "constant" until satellite observations during the 1980s and 1990s made its variations evident. Before the satellite era, exoatmospheric solar irradiance was estimated from ground-based radiometers using the traditional Langley plot method. Systematic ground-based observations of TSI variability trace back to the Smithsonian Astrophysical Observatory Solar Constant Program established 100 years ago. In the first half of the twentieth century, significant effort was made to estimate the change of TSI from ground-based measurements and its possible effect on Earth's climate. There is no doubt that space-borne radiometers provide direct observations of solar irradiance. But why it is so difficult to monitor the solar variation from ground-based estimates of solar irradiance has not been answered quantitatively. The work reported here provides a definitive conclusion as to the inadequacy of monitoring of solar variations from ground-based estimates. Indeed, to understand the impacts of solar variations on Earth's climate, one must rely on long-term satellite observations [Wen *et al.* 2003].

Significant effort was made towards understanding the behavior of SOLSTICE solar spectral irradiance, in collaboration with scientists at the Laboratory of Atmospheric and Space Physics (LASP) at the University of Colorado. A quasi-annual behavior of SOLSTICE solar irradiance has been found in certain wavelengths of the spectrum. A long time series—nearly a solar cycle—was analyzed in this study. The 11-year solar cycle, and 27-day solar rotation variation are evident in SOLSTICE solar spectral irradiance. The observation suggested that the complexity of the temporal variation of solar irradiance was a function of wavelength. For such a nonlinear, nonstationary time series, the mutual information technique was applied in the analysis; initial results suggest a 360-day cycle in some spectral regions for SOLSTICE solar spectral irradiance. Research on the predictability of solar spectral irradiance was also conducted. The analog method was applied to observed SOLSTICE solar spectral irradiance. In this method, the phase space is reconstructed from the observed time series of solar irradiance. The analysis demonstrates the predictability of solar spectral irradiance as a function of wavelength.

Objectives for the Coming Year

The main objective for the coming year is to continue investigating clear sky atmospheric radiative transfer. To accomplish this, variety satellite and ground radiometer measurements will be used. One objective is to look at Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal and Emissions Radiometer (ASTER), and Multi-Angle Imaging Radiometer (MISR) images of the Amazon or other regions around the world. With the availability of different spatial resolutions and angular capability, some interesting results are

expected for the cloud and aerosol studies. The SOLSTICE time series investigations will continue at finer spectral resolutions. In particular, SORCE will provide accurate observations of both total and spectral solar irradiance.

Task 924-21-142: **(a) Water Vapor and Cloud Detection Validation for Aqua Using Raman Lidars and AERI; (b) Using Radar, Lidar, and Radiometer Measurements to Classify Cloud Types and to Study Middle-Level Cloud Properties; (c) CloudSat Level 2 Combined Radar and Lidar Cloud Scenario Classification Standard Product Development**

GEST Investigator: Zhien Wang

Collaborators: David Whiteman (PI, GSFC), Belay Demoz (GSFC), Kenneth Sassen (University of Alaska)

Abstract

To estimate possible effect of thin cirrus clouds on retrievals of water vapor using IR sensors such as the Advanced Infrared Sounder (AIRS) and the Geostationary Operational Environmental Satellites (GOES), subtropical cirrus properties, measured during the Convection and Moisture Experiment (CAMEX)-3 experiment by the GSFC Scanning Raman Lidar (SRL), were analyzed. To establish the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site as central site for AIRS validation, an intensive filed observation was organized to provide upper tropospheric water vapor measurements with different sensors. The primary analysis of this field campaign was finished; it provides important observations to validate the AIRS forward model. As part of the CloudSat standard product algorithm developing team, the GEST investigator delivered the Version 2 cloud scenario classification code to the CloudSat data analysis center at Colorado State University. Under development during this period was the combined lidar and radar cloud classification algorithm, using CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) measurements, and version 0 code was delivered. Because mixed-phase clouds are important in the Earth's climate system but are poorly understood, a new retrieval algorithm for a simple type of mixed-phase cloud (altocumulus with ice virga) was proposed, based on ARM Clouds and Radiation Testbed (CART) site observations.

Description of Research

This research, funded by NASA and the Department of Energy (DOE) ARM program, is comprised of three main components. The first is to study the influence of thin cirrus clouds on the retrievals of water vapor, using IR sensors such as AIRS and GOES, and to provide reliable observations of upper-tropospheric water vapor for AIRS validation. The second is to develop algorithms for two CloudSat standard products: radar-only and combined lidar-radar cloud scenario classifications. CloudSat will be launched early in 2005, and will provide essential measurements of clouds globally. The third area of focus is to develop new ground-based algorithms to study mixed-phase cloud and cloud type based on ARM CART site observations. The goal of all this research is to better understand cloud-radiative feedback and the atmospheric water cycle.

Accomplishments during the Reporting Period

Cirrus clouds affect Earth's radiation budget strongly through both albedo and greenhouse effects, and their high occurrence, especially in the tropical regions, results in some challenges in retrieving water vapor profiles in the presence of thin cirrus clouds using IR sensors. To evaluate the possible effects of thin cirrus clouds, radiative properties of subtropical cirrus, derived from long-term SRL measurements during CAMEX-3, were analyzed and compared with their midlatitude counterparts. These data represent one of the largest series of measurements of cirrus in tropical and subtropical regions from a high-quality Raman lidar instrument.

To validate AIRS water vapor retrievals, especially for upper-tropospheric water vapor, a series of SRL and radiosonde measurements were taken from 28 October 2003 to 19 November 2003 at the SGP CART site. The goal of this field campaign was to establish the ARM SGP site as central site for AIRS validation by intercomparing different radiosondes (*i.e.,* Vaisala 80, 90, and 92; Intermet; Sippican; the University of Colorado Cryogenic Frost point Hygrometer (CU CFH); and Snow white) and Raman lidars (*i.e.,* the CART Raman Lidar (CARL) and the SRL). Preliminary analysis of data from this field campaign was finished, the results of which showed systematic differences between the different sensors. Further analysis will provide reliable observations to validate the AIRS forward model.

Cloud scenario identification is an important step in applying remote sensing algorithms for cloud property retrieval because of the different microphysical and radiative properties of water, ice, and mixed-phase clouds. The Version 2 radar-only cloud scenario classification algorithm was delivered to the CloudSat data analysis center at the Colorado State University, and was improved using different test data sets. Funding was received to combine satellite-based lidar and radar cloud classification algorithms using CloudSat radar and CALIPSO lidar measurements. CloudSat radar and CALIPSO lidar measurements were simulated using Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) ER-2 cloud physics lidar (CPL) and the Cloud Radar System (CRS). The Version 0 lidar-radar code based on these simulated data was developed and was delivered to the CloudSat data analysis center.

There were two main achievements under the DOE ARM-funded research. First, a new approach to study mixed-phase clouds was developed. Precipitating altocumulus clouds are a common type of mixed-phase clouds, and their easily identifiable structure provides a simple scenario to study mixed-phase clouds. Ice virga was treated as an independent ice cloud, and an existing lidar-radar algorithm was applied to retrieve ice water content and general effective size profiles. A new iterative approach was then used to retrieve supercooled water cloud properties by minimizing the difference between Atmospheric Emitted Radiance Interferometer (AERI)-observed radiances and radiances calculated using the discrete ordinate radiative transfer model at 12 selected wavelengths. Case studies demonstrated the capabilities of this approach in retrieving radiatively important microphysical properties to characterize this type of mixed-phase cloud. Second, an improved cloud classification algorithm was developed, based on SGP CART site observations. This algorithm will be used to generate an operational cloud-type product, an important step in producing an integrated cloud product from ARM data streams.

Objectives for the Coming Year

Work in the coming year will include combining the Raman lidar and satellite measurements to study the effect of optically thin cirrus clouds on the retrieval of precipitable water from satellite measurements. The AIRS Water Vapor Experiment (AWEX) data analysis will conclude, and a water vapor database for AIRS validation and retrieval algorithm improvement will be generated. The radar-only cloud classification algorithm for CloudSat project will be improved and refined, and development of a satellite-based combined lidar and radar cloud classification algorithm will continue. New algorithms will be developed to study mixed-phase clouds from ARM ground-based observations and more analysis mixed-phase observations at ARM CART sites will be done. A new Raman lidar technique will be developed to measure ice cloud microphysical properties using ice crystal Raman scattering.

Task 971-20-137: **Remote Sensing of Sea Surface Salinity**

GEST Investigator: Kevin Horgan

Collaborators: Fernando Pellerano (PI, GSFC), Jeff Piepmeier (GSFC), Edward Kim (GSFC)

Abstract
Research in ultra stable radiometry is being performed to develop an advanced precision space-borne radiometer to measure sea surface salinity (SSS). This research has been conducted under an instrument incubator program (IIP) at GSFC, and is a precursor to the upcoming Aquarius mission. Research into the RF power detectors used in a testbed radiometer resulted in improved models to mitigate their nonlinear response. Microwave mismatches discovered during IIP testing also resulted in an improved design for the follow-on microwave integrated circuit (MIC) engineering model for the Aquarius flight hardware. A cryogenic calibration target was also characterized, helping to improve knowledge of this standard, which is necessary for long-term stability tests.

Description of Research
The research performed under this task addresses microwave remote sensing technology to develop microwave radiometers and polarimeters with application to SSS remote sensing. This work involves research and development of prototype radiometers for the Aquarius mission to assess its accuracy and stability performance requirements. The research seeks the optimum radiometer configuration and calibration procedures to meet Aquarius project objectives. Particular attention is paid to radiometric stability and polarimetric detection and calibration.

Accomplishments During the Reporting Period
The GEST investigator performed extensive testing of RF power detector nonlinearity to enable team members to develop a correction model to remove gain expansion and compression effects. During nonlinearity testing a mismatch of the Dicke switch between the antenna and reference load ports was measured. Further investigation revealed this mismatch was caused by imperfect coupler isolation following the Dicke switch, which was mitigated by placing an isolator before the coupler. This modification has been incorporated into the next series of radiometers, currently under design. The research also characterized a cryogenic calibration target, and helped determine temperature distribution, connector losses, and mismatches for the L-band ultrastable calibration load. Knowledge of this target is critical to successful long-term radiometer stability tests of engineering models for the Aquarius mission.

Objectives for the Coming Year
Work in the coming year will upgrade the single-channel, bench-top radiometer to a four-channel MIC polarimetric radiometer with V-pol, H-pol, +45 and –45 linear polarization outputs. Much of the previous RF testing will be repeated on the upgraded instrument, validating the design for the follow-on engineering model radiometer and eventual flight hardware. Testing of the MIC radiometer in the cryogenic test-bed will take place to simulate orbital temperature variations with a 90-minute period, and to ensure the design meets mission stability requirements.

Task 975-32-159: **A Study of Microwave Rader on Estimates of Hydrometeor Profiles**

GEST Investigator: Liang Liao

Collaborator: Robert Meneghini, (PI, GSFC)

Abstract
This research addresses applications of airborne and spaceborne weather radar to retrieve microphysical properties of hydrometeors. The work includes theoretical modeling and simulation of radar signatures in the rain, snow and mixed-phase media, analysis of the radar measurements, and validating radar algorithms to derive characteristic precipitation parameters. The work in the reporting period have four foci: use of dual-wavelength airborne radar for snow parameter estimates; evaluating spaceborne radar attenuation by radar mirror images (MI); simulating airborne radar to estimate rain profiles; and using ground-based instruments to validate spaceborne radar's rain estimates.

Description of Research
Research topics addressed in this work include simulating polarimetric radar returned from stratiform and convective rain to interpret dual-wavelength, polarimetric radar measurements; developing radar algorithms to retrieve hydrometeor properties; analyzing and comparing measurements from spaceborne radar and ground-based measurements to validate radar algorithms; implementing mirror-image algorithms to process Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) data to examine TRMM's standard algorithms to estimate rain path attenuations; deriving and examining the effective dielectric constant of mixed-phased hydrometeors and its application in detecting the melting layer of stratiform rain by microwave radar.

Accomplishments during the Reporting Period
Using dual-wavelength radar (with properly chosen wavelengths) to estimate snow parameters will significantly lessen the ambiguities in retrieving hydrometeor microphysical properties. A dual-wavelength algorithm was described to estimate the characteristic parameters of the snow size distributions. Analysis of the computational results, made at X and Ka bands (using the T-39-based airborne radar) and at S and X bands (using the CP-2 ground-based radar), indicates that accurate estimates of the median volume diameter of snow particles, D_0, should be possible if one of the two wavelengths of the radar operates in the non-Rayleigh scattering region. To examine the validity and accuracy of the dual-wavelength radar algorithms, the algorithms were applied to data taken from the Convective and Precipitation-Electrification Experiment (CaPE), performed in 1991, in which the dual-wavelength airborne radar was coordinated with *in situ* aircraft particle observations and ground-based radar measurements. Having carefully coregistered the data obtained from the different platforms, the airborne radar-derived size distributions were then compared with the *in situ* measurements and ground-based radar. Good agreement was found for these comparisons, despite the uncertainties resulting from mismatches of the sample volumes among the different sensors and spatial and temporal offsets.

Using spaceborne radar attenuation by MI returns to estimate rain attenuation is based on the observation that the difference between the direct and MI returns at equal distances from the surface, as reflected in MI simulations, is directly related to rain path attenuation. However, the accuracy of the MI method for inferring the attenuation relies strongly on radar geometry, with such factors as the antenna beam width and the radar altitude playing key roles. Two approaches, using direct returns and MI and surface returns, were studied for path attenuation retrieval. The MI algorithms were applied to TRMM PR measurements. Comparisons with the PR algorithm results—as well as the surface return technique (SRT) and the Hitschfeld-Bordan method—are made using consecutive PR measurements over the period 1-15 February 1998. Analysis of the results revealed that the path attenuation from the PR algorithm is in reasonable agreement with those estimated by MI algorithms. The results of using the SRT and

Hitschfeld-Bordan method with the same data set are consistent with MI algorithm estimates.

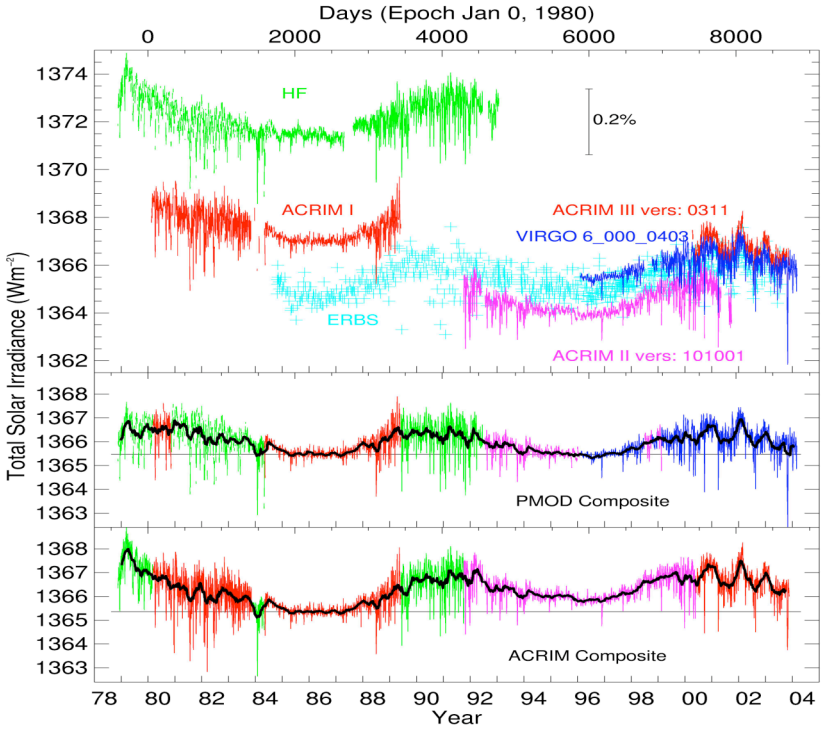
Dual-wavelength radar has shown promise in improving estimates hydrometeor microphysical properties if one or both wavelengths operate in the non-Rayleigh region. However, the radar signal is attenuated in rain. This complicates procedures for radar retrieval of rain rate and affects the accuracy of the algorithms if the attenuation is not properly corrected. In this study, the primary focus is on an evaluating air- and spaceborne dual-wavelength radar algorithms to estimate characteristic hydrometeor parameters. To validate the algorithms and examine their accuracy, a rain model was established to characterize the hydrometeors' vertical profile. Raindrop size distributions (DSD), obtained from disdrometer measurements and expressed in the form of a gamma function, are used to construct the rain profiles. The DSD data, recorded in time sequences, are transformed to vertical DSD profiles in the model so that the synthetic rain profiles capture, in an approximate way, the change in DSD with height. The melting layer, or bright band, is also included in the model to account for the full-path radar signal attenuation. A bright-band model that provides coupling particle melting with dynamic and thermodynamic processes within the melting layer is used along with the scattering model of melting snow to generate the DSD parameters of melting snow and its radar profile.

Progress has been made in the processing of ground-based radar data and comparing these results with collocated satellite radar estimates of reflectivity and rainfall rate to validate spaceborne radar-based estimates of rain by using ground-based measurements. The processing programs have been automated and used by other groups at GSFC to validate satellite-based estimates. Instantaneous and statistical comparisons between the satellite-derived and ground-based measurements are made over five years of observations. The findings are very valuable for assessing spaceborne radar's capabilities to estimate rainfall rate.

Objectives for the Coming Year

Research in the coming year will continue on a variety of topics, including airborne and spaceborne weather radar analysis generally, and the TRMM PR, specifically. The work includes single- and dual-wavelength radar analysis of the melting layer, developing the theory and application of the effective dielectric constants of the mixed-phase hydrometeors, retrievals of the microphysical properties and characteristic parameters of drop size distribution using data from a dual-wavelength airborne weather radar, and validating TRMM PR-derived rain rates using ground-based radar data.

Atmospheric Chemistry and Dynamics Research Group



The upper panel shows the various total solar irradiance time series from the measurements of the Nimbus-7/ERB (HF), SMM/ACRIM I and UARS/ACRIM II, ACRIMSAT/ACRIM III, ERBS, and the SOHO/VIRGO experiments on their original scale. The middle and lower panels show the two composite total irradiances, compiled from the measurements shown on the upper panel.

As can be seen, the PMOD Composite shows a rather symmetric variation of total irradiance with the same minimum levels during solar cycles 21 and 22. In contrast, the ACRIM Composite shows a slight secular trend, i.e., the minimum of cycle 22 is being higher with about 0.05% than the minimum of cycle 21.

Figure provided by Judit Pap

Atmospheric Chemistry and Dynamics Research Group

Members of the Atmospheric Chemistry and Dynamics Research Group investigate atmospheric distributions of trace gases and aerosols, and examine the spectral and geographical distributions of the radiation fields and their impacts on the climate system. Activities of group members span measurement and retrieval processes, data analysis, and modeling.

Data from space-based assets describe the incident solar irradiance and allow accurate estimates of its absorption in the atmosphere and at the surface. Judit Pap's studies of the subtle variability of the incident solar radiation field improve our understanding of one of the primary forcing mechanisms for the Earth system. Pap is also reconstructing historical records of solar irradiance and variability, to be used to understand past climate forcing.

Christina Hsu uses measurements from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instruments, in addition to Total Ozone Monitoring Spectrometer (TOMS) data to retrieve aerosol properties. She applies these to the study of direct radiative forcing due to tropospheric aerosols. Nickolay Krotkov used satellite measurements to develop algorithms to infer the spatial distribution of UV radiation at the surface from TOMS data. He focused on validating the satellite determinations using ground-based measurements. Measurements were also conducted to quantify absorbing aerosol properties in the UV and to determine direct aerosol forcing of surface irradiance. Radiative transfer modeling was extensively used to validate the determination of column aerosol absorption and to ensure consistent aerosol retrievals at UV and visible wavelengths.

An algorithm to infer nitrogen dioxide distribution has been developed by Eric Bucsela using Global Ozone Monitoring Experiment (GOME) measurements.

The effects of aerosols must also be accounted (and corrected) for in remote retrieval of atmospheric temperature and moisture. Clark Weaver's research has focused on the impacts of aerosols, derived from MODIS data, on measurements from the Tiros Operational Vertical Sounder/High-Resolution Infrared Radiation Sensors (TOVS/HIRS) instruments. His work shows that improvements in space-based estimates of surface and lower-tropospheric temperature arise by accounting for moderate dust loading in the tropical Atlantic.

Understanding the distribution and secular changes in ozone is the basis for many of the research studies performed by members of this research group. Jerry Ziemke and Sushil Chandra continued their derivations of tropospheric and stratospheric ozone columns from TOMS measurements using their Convective Cloud Differential method. These global data sets cover the available satellite record since 1979. In addition to developing public-domain data products for NASA, this research, combining measurements and photochemical transport models, has led to substantial new understanding of the dynamics and sources/sinks of tropospheric ozone. Ozone profile analyses, computed by Joan Rosenfield using a zonally symmetric chemistry-transport model, show negative trends resulting from increasing chlorofluorocarbons, in good agreement with Solar-Backscattered Ultraviolet (SBUV) data at low latitudes. Other model simulations suggest that tropical ozone depletion in the 40-60 mb region will not recover.

Gary Morris used the GSFC trajectory model with data from balloon-borne ozonesondes to derive ozone loss rates in the lower stratosphere for periods of intensive field studies that focused on atmospheric chemical processes.

Research by Mark Olsen has shown that more midlatitude cross-tropopause ozone transport occurs in the Northern Hemisphere (NH) than the Southern Hemisphere (SH), due primarily to greater ozone concentrations (and not dynamical differences) near the NH midlatitude tropopause. There is a shift of one month in the maximum cross-tropopause fluxes between the hemispheres. Research on the amount of water vapor transported from the Asian monsoon to the tropical stratosphere has led to testing and refinement of a new adjoint version of the Goddard Parameterized Chemistry and Transport Model.

The capability of studying both tropospheric and stratospheric photochemistry in a consistent way in Chemistry and Transport Models (CTMs) is needed to improve our understanding of atmospheric chemistry and the climate system. A new initiative was organized in Goddard's Atmospheric Chemistry and Dynamics Branch to move the effort in this direction. Current studies, being performed by Huisheng Bian, have established a common CTM framework, including all dynamical processes required for future chemistry model development. This model framework is concise in structure, efficient in data management, "user friendly" in model application, and is easily upgraded.

Several new diagnostics for stratospheric transport processes were developed by Susan Strahan using analyses of Upper Atmosphere Research Satellite (UARS) CH_4 data sets. These diagnostics have been applied to evaluate model transport in two Global-Modeling Initiative (GMI) 36-year ozone trend simulations. These diagnostics are also being applied to a series of CTM sensitivity studies to understand how model implementation affects constituent distributions. The first sensitivity study compares online and offline (CTM) chemical calculations with identical spatial resolution. Initial evaluation indicates that the offline calculation introduces negligible differences to the long-lived tracer distributions. Bryan Duncan initiated an analysis of the results of the tropospheric simulation of the NASA GMI 3-D chemistry and transport model (CTM). GMI activities in the coming year will focus on evaluating the model's output to assess the ability of various modules to reproduce atmospheric observations. Another study will be initiated of the impact of pollution from forest fires on surface ozone in the extratropical Northern Hemisphere using the GEOS-CHEM CTM.

Mohan Gupta has coupled GSFC stratospheric chemistry into the GSFC finite-volume General Circulation Model (fvGCM), and performed initial tests of its implementation and performance. His second, related study involved the intercontinental transport of the inert tracer radon (Rn) and its meteorological dependence using the 'online' fvGCM and 'offline' CTM frameworks. The CTM used in this study employed meteorological input from the fvGCM and the finite-volume Data Assimilation System (fvDAS) models. This study also concentrated on quantifying the contributions from regional emissions on the atmospheric loading of Rn at various receptor locations around the globe.

Because of the nature of the areas of study, the work of the Atmospheric Chemistry and Dynamics group is having significant impact on research across the broad range of topics that are addressed by NASA's Earth Science Enterprise, and other Earth system science research generally.

Robert J. Curran (Acting)

Task 900-37-172: **Evaluation of Tropospheric Processes in Simulations Using the Global Modeling Initiative Chemical Transport Model**

GEST Investigator: Bryan Duncan

Collaborators: Susan Strahan (PI, GEST), Jose Rodriguez (University of Miami), Anne Douglass (GSFC), Jennifer Logan (Harvard University)

Abstract
An analysis began of the results of the tropospheric simulation of the NASA Global Modeling Initiative (GMI) 3-D chemistry and transport model (CTM). This task was initiated in January 2004.

Description of Research
The goal of GMI is to develop and maintain a CTM that can be used to assess the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. The CTM is designed to incorporate different modules, such as meteorological fields, chemical mechanisms, numerical methods, and other modules representing the different approaches taken by current models. The approach used here will allow the model to identify the impacts of the different approaches on the model's results. A high priority is to evaluate the GMI model's simulation of the distributions and concentrations of tropospheric trace gases with observations.

In other work, a model study will examine the impact of forest fires in North America and Russia on surface ozone (O_3), especially in heavily populated regions. Boreal forest fires are a significant source of trace gases and aerosols to the troposphere, especially in summer in the midlatitudes, when the photochemical production of O_3 is at its annual maximum. Recently, it was shown that pollution from boreal forest fires could undergo long-range transport and elevate the concentrations of surface air pollutants in the continental United States. Despite the significant, but episodic, impact of pollution from forest fires on surface O_3 in heavily populated regions of the world, there has been few attempts to assess the causes of the annual variation in these fires, to identify the major long-range transport pathways of the pollution, or to quantify the relative impact of the pollution on surface O_3. In addition, the impact of pollution from boreal forest fires on summertime surface O_3 is likely to grow during this century as the Polar Regions warm and dry in a global-warming scenario, resulting in an increase in fire activity. More importantly, an increase in boreal forest fire activity is likely to impact global climate as more than 30% of the worlds terrestrial carbon is found in boreal forest trees, peat, and soils. Variations in area burned in the boreal forests are largely related to year-to-year variations in climate, as most area burned is attributable to fires initiated by lightning. It is essential to understand the connections between climatic phenomena, such as the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), and the interannual variation of naturally-occurring forest fires in the extratropical regions of the Northern Hemisphere to predict the frequency of these fires and their impact on climate and air quality in a world that is warming.

Accomplishments during the Reporting Period
Since joining GEST late in the reporting period, the GEST investigator has lead the evaluation of software packages to be used in the visualization and analysis of chemistry and transport model output of tropospheric constituent distributions. Preliminary analyses of the model's output have been initiated using these software packages.

Objectives for the Coming Year
The GMI activities in the coming year will focus on evaluating the model's output to assess the ability of various modules to reproduce observations. These observations will include measurements taken at ground stations and aboard sondes, aircraft, and satellites. In particular, an attempt will be made to interpret spectra from the Advanced Infrared Sounder (AIRS) aboard the Earth Observing System (EOS) Aqua satellite to estimate tropospheric concentrations of CO. The usefulness for model validation of other

tropospheric trace gas measurements obtained with spaceborne instruments will also be evaluated.

For the second project, a study will be initiated using the Goddard Earth Observing System (GEOS)-CHEM CTM to identify major pollution transport pathways from forest fires in the extratropical regions of the Northern Hemisphere from the 1990s until the present; and to assess the impact of pollution on summertime surface ozone O_3 in the industrialized regions of North America, Europe, and East Asia. In addition, the model will be used to explore the connections between large-scale climate phenomena (*e.g.,* ENSO, PDO, and the North Atlantic Oscillation [NAO]) and interannual variations in forest fire activity in the 1980s and 1990s.

Task 910-01-014: **Radiative Transfer and Zonally Symmetric Atmospheric Modeling**

GEST Investigator: Joan E. Rosenfield

Collaborator: Mark R. Schoeberl (PI, GSFC)

Abstract

Ozone profile trends computed using a zonally symmetric model of stratospheric chemistry and transport were compared to observations from the Solar Backscatter Ultraviolet (SBUV) instruments. Negative trends between 1980-2001 were a result of ozone depletion due to increasing chlorofluorocarbons in the stratosphere. Model trends agree well with observations in the low latitudes, but underestimate the observed trends at higher latitudes. Trends are largest in the high-latitude upper stratosphere in winter for both the model and data. In other work, chemical model simulations of ozone recovery suggest that tropical ozone depletion in the 40-60 mb region will not recover.

Description of Research

The radiative transfer model, developed by the GEST investigator, is used to calculate global three-dimensional stratospheric and tropospheric heating rates from analyzed temperature fields. The research community uses these heating rates in calculations of diabatic parcel trajectories. The radiative transfer model also constitutes a module in the GSFC zonally symmetric atmospheric model. This zonally symmetric model couples chemistry, radiation, and dynamics, and is being used to study the current and future state of the ozone layer. The task also includes adapting and/or developing improved parameterizations in the radiative transfer model.

Accomplishments during the Reporting Period

Computed stratospheric ozone profile trends were compared with observations. The ozone profile trends were computed as a function of latitude and height for the period 1980-2001, using output from the zonally symmetric coupled model and a statistical time series analysis. The observations are from the SBUV and SBUV/2 instruments. The observational dataset is a new SBUV merged data set, in which observations from the SBUV instruments on various satellites have been combined, using a time-dependent calibration adjustment that is based on comparisons with Stratospheric Aerosol and Gas Experiment (SAGE)-II profiles. The resulting internally consistent ozone profile data set is suitable for trend analysis. Annual mean and seasonal trends have been compared. Ozone profiles exhibited negative trends during this period, due to the increasing amounts of chlorofluorocarbons in the stratosphere. The annual mean model trends agree well with observations in the low latitudes, but underestimate the observed negative trends in the higher latitudes. Maximum negative trends for both the data and the model are in the high-latitude upper stratosphere, with southern hemisphere trends being more negative than northern hemisphere trends. Trends in the winter are generally more negative than those in the summer for both the data and the model. The greater trend in winter was shown to be the result of greater chlorine activation due to the much colder winter temperatures. The model results show that ozone trends computed from profiles recorded at

geometric altitudes differ from those recorded at pressure levels. In addition, trends computed from mixing ratio profiles differ from those computed from number-density profiles. This will be true whenever a temperature trend is present, and is important to keep in mind when comparing trends from various instruments.

An interesting result from the chemical model simulations of ozone recovery is that the tropical ozone depletion in the 40-60 mb region is predicted not to recover. There appears to be nothing in the literature that suggests this. Preliminary work shows that this lack of recovery is due to a combination of heterogeneous chemical loss on sulfate aerosol particles and cooling of the stratosphere, due mainly to carbon dioxide.

Collaboration with J. Ajtic, a student of B.J. Connor in New Zealand, studied the dilution of the Antarctic ozone hole into southern midlatitudes. This work was done using the radiative heating rates in a trajectory.

A version of the radiation model incorporating infrared heating due to the greenhouse gases methane and nitrous oxide was developed. The code developed by M. D. Chou was adopted for this purpose.

Objectives for the Coming Year

Work will continue in studying the predicted lack of recovery of tropical lower stratospheric ozone depletion, including the extent to which UV-B radiation entering the troposphere and reaching the surface is increased. The newer version of the radiative heating code will be incorporated into the coupled zonally symmetric model, and the ozone recovery predictions and the computed ozone profile trends will be reexamined.

Task 910-04-074: **Observationally Based Evaluation of Chemical and Transport Processes in Atmospheric Models**

GEST Investigator: Susan Strahan

Collaborator: Anne Douglass (PI, GSFC)

Abstract

Several new diagnostics for stratospheric transport processes were developed using analyses of Upper Atmosphere Research Satellite (UARS) CH_4 data sets. These observational analyses serve as diagnostics for model transport processes, and have been applied to two NASA Global Modeling Initiative (GMI) 36-year ozone trend simulations to evaluate the credibility of model transport. These diagnostics are also being applied to a series of GSFC chemistry and transport model (CTM) sensitivity studies to understand how model implementation affects constituent distributions. The first sensitivity study compared online and offline (CTM) chemical calculations with identical spatial resolution. Initial evaluation indicates that the offline calculation makes negligible contributions to the differences in long-lived tracer distributions. The GMI, a NASA modeling and assessment project, moved to GSFC last year. To manage this project, a team of scientists, programmers, analysts, and software engineers has been assembled to support all core modeling activities, which include model integration, evaluation, maintenance, and development.

Description of Research

This research focuses on interpreting and analyzing stratospheric trace gas observations and applying those analyses to three-dimensional atmospheric models. The goal of the data analysis is to better understand the balances between photochemistry and transport for stratospheric ozone and other constituents. The data analyses, scientifically important by themselves, are also used to evaluate the performance of models. The models evaluated are the Goddard 3-dimensional Chemistry and Transport Model (3-D CTM) and the GMI 3-D CTM. These models are used to investigate anthropogenic influences on the stratosphere and to estimate possible future trends based on changes in surface emissions.

Accomplishments during the Reporting Period

Several new diagnostics for stratospheric transport processes were developed by analysis of UARS CH_4 data sets. A one-year extratropical CH_4 data set from the Cryogenic Limb Array Etalon Spectrometer (CLAES) instrument was used to examine seasonal variations in poleward transport and mixing in middle and upper stratosphere. An analysis of eight years of Halogen Occultation Experiment (HALOE) CH_4 data in the Antarctic examined how the vortex breaks down and mixes with the surrounding air in spring. These observational analyses serve as diagnostics for model transport processes, and have been applied to two GMI 36-year ozone trend simulations to evaluate the credibility of model transport. These diagnostics are also being used to interpret the different responses shown by the two GMI simulations to changing chlorine levels.

Transport diagnostics are being applied to a series of CTM sensitivities studies to understand how model implementation affects constituent distributions. A CTM is an offline chemical transport model that uses wind fields from another meteorological model. The circulation, transport, and mixing processes in a CTM are not only a function of the input wind fields, but also of many aspects of its implementation, such as horizontal and vertical resolution, height of the model domain, and whether or not the input winds have been interpolated in space or time. The first CTM sensitivity study compares an online chemical calculation with an offline (CTM) calculation using the same spatial resolution. Initial evaluation, using the diagnostics described above, indicates that the offline calculation introduces negligible differences in long-lived tracer distributions.

Three versions of the GMI model – for stratospheric, tropospheric, and aerosol calculations – were delivered by the Lawrence Livermore National Laboratory to the GSFC core modeling team last summer. The core modeling team, responsible for maintenance, development, and integration of the GMI models, has begun to learn the model codes and how to modify them. Several new tropospheric simulations have been integrated and delivered to the GMI Science Team, which consists of scientists from many universities and government labs. A GMI Web page has been created, which serves to explain the purpose of the organization and to provide software and support for GMI team members using GMI model output.

Objectives for the Coming Year

The CTM sensitivity studies will continue. Experiments will include testing the effect of lowering the model lid from the upper to the middle mesosphere, reducing the number of vertical levels, and increasing and decreasing the horizontal resolution. This series of experiments will make one change at a time to the model so we may understand exactly how each change affects model performance and credibility. The knowledge gained from these sensitivity studies is relevant to both the GSFC CTM and the GMI CTM.

Management of the GMI project will be the major focus of this investigation. Experiments planned for the stratospheric model include a horizontal resolution sensitivity study and an ozone hindcast, wherein both past ozone and future ozone are simulated. To some degree, the model's credibility will be judged by how well it simulates late-twentieth-century ozone. Many experiments are planned for the tropospheric model, including both simple tracer and full chemistry experiments. The simple tracer experiments help to diagnose the full chemistry experiments by separating the effects of transport and chemistry. The GMI aerosol model is the newest addition to this project. Many simulations are planned to test the effects of various chemical and meteorological inputs on aerosol distributions. All model output will be more thoroughly evaluated by to-be-developed standardized evaluation packages before distribution.

Task 910-04-074: **Assimilation Studies**

GEST Investigator: Clark Weaver

Collaborators: Arlindo da Silva (PI, GSFC), Mian Chin (GSFC), Joanna Joiner (GSFC), Loraine Remer (GSFC)

Abstract

The two main research topics addressed under this task are the development of an aerosol assimilation system using Moderate Resolution Imaging Spectroradiometer (MODIS) radiances, and the improvement of temperature and moisture retrievals from TOVS radiances by including the radiative effects of mineral dust aerosols. An off-line system has been developed for the assimilation of aerosol optical properties utilizing visible and near infrared radiances measured by the MODIS instrument on the Earth Observing System (EOS) satellite platforms. Mineral aerosols have strongly absorbing spectral features in the infrared. Consequently, there may be errors in TIROS Operational Vertical Sounder (TOVS) retrieved temperature and moisture profiles in regions of heavy dust loading.

Description of Research

This task has two research foci. In developing an assimilation system for atmospheric aerosols, the system uses radiances in the visible and near infrared as measured by the MODIS on EOS satellite platforms. Satellite-measured radiances are used to identify atmospheric aerosols over dark oceanic surfaces. The second study addresses the radiative impact of aerosols on the infrared radiances used in determining atmospheric temperature and moisture profiles. Radiances used in the second study are from the TOVS High-resolution Infrared Radiation (HIRS) instruments on National Oceanic and Atmospheric Administration (NOAA) operational satellites.

Accomplishments during the Reporting Period

To initiate the calculations, the Global aerosol Chemistry-Aerosol Radiation-Transport (GOCART) model provides three-dimensional aerosol spatial distributions. Using the multiple-scattering radiation transfer model developed at the University of Arizona, *a priori* MODIS-like radiances are calculated for the aerosol species given in the GOCART model. These forward calculations are organized for tabular "look-up." A variational approach is used to produce aerosol distributions by modifying the GOCART aerosol concentrations to minimize the differences between the simulated radiances and those observed from MODIS. A first version of the MODIS aerosol assimilation system has been developed that only inserts MODIS radiance information over ocean. A second version of this system that assimilates radiances over land is currently being developed.

The second area of study under this task addresses the effect of mineral aerosol absorption in the Optical Path Transmittance Model (OPTRAN), which is used for satellite temperature and moisture retrievals by the National Centers for Environmental Prediction (NCEP). Additional analyses are in progress to determine whether TOVS radiances are being assimilated into the NCEP products in locations of low-to-moderate dust loading, based on the TOMS aerosol index.

Objectives for the Coming Year

In the coming year, the MODIS aerosol assimilation system will be enhanced to assimilate radiances over land. The higher reflectance of most land surfaces make isolation of the aerosol effects more difficult than the lower-reflectance ocean surface. Ultimately, the goal of this effort is to provide a system capable of assimilating global aerosol characteristics.

A project related to the development of the aerosol assimilation system is to analyze radiances from MODIS observations of different types of aerosols over coastal oceans. After accounting for satellite geometry and contributions of the ocean surface, the radiances will be analyzed to determine if there is a unique spectral signature for a given type of

aerosol. This should provide validation for look-up-tables used in aerosol retrievals and assimilation.

Finally, a project is under consideration involving the development of techniques to infer vertical profiles of CO_2 from very-high-spectral-resolution measurements from a Fabry-Perot interferometer.

Task 913-13-120 and Task 916-08-101: **Calculation of Radiative Forcing of Aerosols and Clouds Using Satellite and *In Situ* Measurements**

GEST Investigator: Nai-Yung Christina Hsu (PI)

Collaborators: Si-Chee Tsay (GSFC), Jay R. Herman (GSFC), Michael King (GSFC), Jeff Reid (NRL)

Abstract

Continued attention has been paid to improving methods to retrieve aerosol information from satellite data and in applying these approaches to understand the role of aerosols in Earth's climate. Specifically, computational algorithms have been enhanced to retrieve aerosol properties such as optical thickness, Ångstrom exponent and single-scattering albedo from satellite measurements over brightly reflecting surfaces. The satellite measurements were obtained using the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite-based instruments. Research continued to determine direct forcing due to tropospheric aerosols by combining aerosol information derived from the visible/near infrared (NIR) SeaWiFS and MODIS channels with those from the UV channels of the Total Ozone Mapping Spectrometer (TOMS). Radiative flux measurements were provided by the Clouds and the Earth's Radiant Energy System (CERES) instruments on several satellite platforms.

Description of Research

Part of this task is devoted to developing data sets from various satellite-based instruments to address aerosols, water vapor, and other products suitable for estimating radiative forcing due to tropospheric aerosols and clouds. Top-of-atmosphere and bottom-of-atmosphere radiative flux measurements observed by satellite and ground-based instruments are simulated using radiative transfer codes under various conditions.

Accomplishments during the Reporting Period

A proposal was funded through NASA's EOS program, with the objective to provide the urgently needed aerosol information from MODIS over urban and desert regions. The ability to determine such aerosol characteristics over these climatically important regions using satellite data has been historically difficult. Our satellite algorithm takes advantage of the fact that the surface reflectance is usually very bright in the red part of the visible spectrum and in the near infrared, but is much darker in the blue spectral region. By combining multispectral information, products of aerosol optical thickness, Ångstrom exponent, and single-scattering albedo over these bright-reflecting surface regions are produced. The validation results show that aerosol optical thicknesses retrieved from SeaWiFS are in reasonable agreement with those measured from by ground-based sun photometers at the Aerosol Robotic Network (AERONET) sites over the Sahara and Sahel region, as well as arid regions in China [Hsu *et al.* 2004].

Through NASA funding of the Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA) grant, studies have continued to determine the direct and indirect effects of smoke aerosols on climate. The smoke aerosol studies used data generated from biomass burning activities in Southeast Asia. The narrowband radiance measurements, from ultraviolet to near-infrared wavelengths (*e.g.,* SeaWiFS and TOMS) were combined with broadband irradiance measurements (*e.g.,* CERES)

to quantify how smoke aerosols modulate cloud radiative forcing. Previously, these collocated satellite measurements were analyzed for March 2000, and it was found that the reflected solar (emitted thermal) radiation from clouds could be reduced (enhanced) by as much as 100 (20) W/m^2. The time series of that study has been extended to the entire dry season (March – April) for both years 2000 and 2002. Preliminary results show that the effect of smoke from biomass burning activity in Southeast Asia on the cloud radiation budget is roughly the same despite the significant differences in cloud properties (such as cloud height and cloud amount) between these two years.

Objectives for the Coming Year

Work in the coming year will continue in refining the SeaWiFS algorithm to determine aerosol characteristics over bright-reflecting surface areas in the globe, which have previously been difficult to measure. An extensive validation effort is planned, to be accomplished by comparing satellite-retrieved aerosol optical thickness with values obtained from the AERONET.

Studies of radiative forcing of tropospheric aerosols will continue, using satellite, aircraft, and ground-based measurements. The aerosol information collected from Aerosol Characterization Experiment (ACE)-Asia will help strengthen our understanding of the aerosol property assumptions used in calculating radiative forcing due to Asian dust.

A new CERES-Terra and SeaWiFS collocated data set will be created to compare the empirically derived values of direct forcing of smoke aerosols generated from biomass burning activities in Southeast Asia with theoretically simulated values to gain further understanding of the processes involved. These results will also be compared with those derived from smoke aerosols generated in other regions of the world, such as South America and Africa.

Task 913-18-130: **Modeling of Rainfall Statistics from Satellite and Ground-Based Remote Sensing Measurements**

GEST Investigator: Prasun K. Kundu

Collaborator: Thomas L. Bell (PI, GSFC)

Abstract

Research efforts under this task involved a detailed study of various aspects of the statistics of gridded monthly averaged rainfall data from the Tropical Rainfall Measuring Mission (TRMM) over the equatorial Pacific. These aspects include secular variations (such as the diurnal—and possible weekly— cycle) and estimating the sampling error using a previously developed theoretical approach, and applying a spectral rain model to describe the spatial statistics of area-averaged rainfall data obtained from the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE). The model successfully describes various features of the rain statistics, including the power law scaling behavior at small spatial scales. Current work focuses on applying the model to describe the statistics of time-averaged rain gauge data collected at the various TRMM ground validation sites as part of an intercomparison study of gauge and satellite precipitation estimates.

Description of Research

Four major research goals are addressed by work under this task: developing mathematical models of rainfall statistics; applying these models to describe the statistical behavior of precipitation data sets from a variety of sources, including satellite- and ground-based remote sensing measurements, as well as rain gauge networks; detailed study of statistics of precipitation data obtained from low-Earth-orbiting satellites, such as TRMM, the Special Sensor Microwave/Imager (SSM/I), and the Earth Observing System (EOS) Aqua, carrying the Advanced Microwave Scanning Radiometer for EOS (AMSR-E); and providing sampling error estimates of gridded

monthly rainfall averages obtained from these global satellite data sets, using a theoretical formula based on previous studies of actual satellite rain data [Bell *et al.* 2001] and numerical simulation of the satellite sampling pattern with realistic orbital dynamics combined with modeled rainfall statistics [Bell and Kundu 1996].

Accomplishments during the Reporting Period

Work continued on a number of applications of the stochastic dynamical model of rain originally developed to describe precipitation statistics during the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE). The model successfully describes various aspects of the spatial statistics of the gridded rainfall data collected during TOGA COARE [Kundu and Bell 2003]. The four parameters of the model spectrum—an overall strength parameter, a characteristic length separating the long- and short-wavelength regimes, a characteristic relaxation time for decay of the autocorrelation of the instantaneous local rain rate, and a certain fractal power law exponent—were tuned to the statistics of rain rate data spatially averaged on a square grid. The model is approximately scale-invariant at small spatial scales, and naturally predicts power-law scaling behavior for several rain-related statistics. Moreover, the scaling exponents are all simply expressed in terms of the single fractional index, which appears as a spectral model parameter. The fractal behavior predicted by the model at small scales agrees well with observations. Recent investigation has led to an underlying physical picture of rainfall evolution based on anomalous diffusion and Levy flights that reproduces the model spectrum. Current work explores a limiting behavior of the spectral model—namely, the invariance of the space-time covariance function of the precipitation field under a combined rescaling of the space and time variables—a property known as dynamic scaling—and seeks evidence for this behavior in precipitation data.

The spectral model was also applied to the intercomparison problem of rain gauge and satellite estimates over an area surrounding the gauges. The model predicts an optimal averaging time for gauge data when gauge averages are compared to the satellite averages (in the sense that it minimizes the root-mean square difference between the two estimates) [Bell and Kundu 2003]. The optimal averaging time decreases as more gauges are added within the area viewed by the satellite. Current work involves applying the spectral model to describe the statistical behavior of time-averaged precipitation data from the multiyear long time series of rainfall collected at several TRMM ground validation sites.

In addition to the work on rain statistical models, work continued on estimating sampling errors for TRMM data using previously developed error models. The extensive effort to gather rain statistics from the entire available TRMM Microwave Imager (TMI) data, initiated last year as a part of a collective TRMM data mining operation, progressed on schedule. Also, theoretical work was initiated with the objective of extracting signals of secular variation of the rain statistics from the long time series of global TRMM data now available.

Objectives for the Coming Year

The immediate goal for the coming year is to investigate the statistics of time-averaged precipitation data from rain gauge networks for evidence of scaling behavior, which would test (and hopefully validate) the spectral model in a broader regime. New exploratory work will seek to extend the spectral model to try and improve the model fit to the temporal covariance function at very small time lags—a deficiency noted in the context of previous work with GATE and TOGA-COARE rain statistics. The original program of studying various aspects of TRMM rainfall statistics will continue as the data mining operation progresses.

Task 916-01-016: **Interactive Global Modeling of Stratospheric and Tropospheric Photochemical Systems Coupled with the Atmospheric General Circulation Model**

GEST Investigator: Mohan Gupta

Collaborators: Anne Douglass (PI, GSFC), Randy Kawa (GSFC), Rich Stolarski (GSFC), Mark Schoeberl (GSFC), Max Suarez (GSFC), Steven Pawson (GEST), Eric Nielsen (SSAI)

Abstract

Research under this task includes two major activities: a study of chemistry-climate interactions through stratospheric ozone, and a study of long-range and subscale transport of atmospheric tracers. In support of the first activity, stratospheric chemistry has been successfully coupled online with the GSFC Finite Volume General Circulation Model (fvGCM). Initial performance tests have been performed and the results analyzed. For the second activity, intercontinental transport of radon (Rn) and its meteorological dependence have been studied using the online fvGCM and offline chemical transport model (CTM) frameworks. The CTM used in this study employed meteorological input from the fvGCM and the finite volume data assimilation system (fvDAS) models. This study also focused on quantifying contributions from regional sources to atmospheric Rn loading at various receptors placed around the globe.

Description of Research

One of the major goals of GSFC's Atmospheric Chemistry and Dynamics Branch (Code 916) is to study atmospheric radiative, dynamical, and chemical interactions in a single modeling framework. This unified modeling approach helps to assess the impacts of natural and anthropogenic perturbations on global and regional atmospheric chemical composition, and their interactions with the climate system. To meet this goal, the chemistry of the troposphere, stratosphere, and mesosphere will be coupled online with the fvGCM. Modeling tools developed under this task will be used to examine important scientific issues, such as future recovery of stratospheric ozone and atmospheric chemistry-climate interactions.

Accomplishments during the Reporting Period

During the reporting period, the GSFC stratospheric and mesospheric chemistry code was successfully implemented in the fvGCM framework, and is known as the GCM-CHEM. Several modifications have been incorporated in GCM-CHEM to utilize adaptable time steps under stiff chemical conditions and to enhance runtime efficiency. Several initial tests have been performed during the development phase to ensure the accuracy of the changes made. At this stage, the GCM-CHEM model is ready for use to investigate stratospheric ozone-related chemistry-climate-dynamics interactions.

The other work under this task deals with simulations of atmospheric radon (Rn), which is considered an ideal tracer to examine the convective and subscale transport in the troposphere. However, there are uncertainties in estimates of its atmospheric emissions. Recent studies have concluded that there is a latitudinal gradient in Rn's surface emissions between 30° N and 70° N. The validity of this conclusion was studied in conjunction with other estimates of Rn emissions. This work has been accepted for publication in *Tellus-B*.

The pathways of intercontinental transport and their meteorological dependence using Rn-like atmospheric tracers in online fvGCM and offline CTM frameworks have been studied. For the fvGCM, atmospheric simulations of eight (one global, seven regional) Rn-like tracers were performed for a decade-long period. In addition to examining tracer distributions in the context of surface concentrations, vertical profiles, and column amounts, the meteorological dependence

of relative contributions made by regional emissions to tracer distributions at 50 receptors placed around the globe have been examined.

Objectives for the Coming Year

During the coming year, research activities will concentrate on two topics: testing, validating, and applying GCM-CHEM to investigate stratospheric chemistry-climate interactions; and examining convective transport in the fvGCM and its implementation in the CTM.

For the first focus, a step-by-step approach will be employed before fully utilizing the benefits of the online GCM-CHEM. Initially, the evolution of stratospheric chemical composition from the GCM-CHEM will be intercompared with that from the stratospheric CTM under identical conditions. Next, the radiative and dynamical effects of changing ozone in the GCM-CHEM framework will be examined by replacing the generalized ozone climatology in the GCM with that derived from the CTM simulation representing two different atmospheric conditions. Based on the analysis from these two steps, the online aspect of chemistry-climate coupling will be examined after replacing climatological ozone fields by the chemically updated fields.

Presently, the GSFC CTM has a provision for parameterized tropospheric ozone chemistry to address the ozone flux exchange across the tropopause and to model upper-tropospheric ozone. This parameterized tropospheric ozone chemistry will be replaced by the interactive chemical scheme representing the chemical composition of the natural background troposphere. Also, presently prescribed lower boundary conditions for the long-lived species in terms of mixing ratios will be replaced by the corresponding surface emissions. Both modifications to the CTM would help to properly address the issues of stratospheric ozone and to interpret the residual tropospheric ozone derived from space-based column ozone observations.

For the second focus, the relative performance of two convective schemes (Zhang McFarlane/Hack, and the Cloud Microphysics-based Relaxed Arakawa-Schubert Scheme, (McRAS)) will be evaluated. Radon will be simulated as a short-lived tracer in an online mode of the fvGCM. Also, offline simulations will be performed in the CTM framework using six-hourly averaged archived meteorological and convective fields from both versions of the fvGCM. The main objective of this latter activity is to intercompare atmospheric distributions of tracers derived from both CTM simulations and from both versions of the fvGCM.

Results from this study will provide some guidance on the need for improvements and sufficiency of convective numerical schemes in the fvGCM and the CTM.

Task 916-01-017: **Investigation and Application of the Match Technique**

GEST Investigator: Gary A. Morris

Collaborators: P.K. Bhartia (PI, GSFC), Mark Schoeberl (GSFC), Richard Stolarski (GSFC), Bojan Bojkov (GSFC), Leslie Lait (GSFC)

Abstract

Results from the GSFC trajectory model are combined with data from ozonesondes to derive ozone loss rates in the lower stratosphere for the Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE, January – March 2000) and for Airborne Arctic Stratospheric Expedition (AASE)-2 (January – March 1992) in an approach similar to Match. Although loss rates derived from this work were similar to those previously published, the largest previously published loss rates for January 1992 were not found. The results of the work reported here are associated with substantially larger uncertainties than found in previous publications. The sensitivity of the Match Technique to a variety of data filters was investigated; it was found that only a filter based on potential vorticity seems necessary. The calculated ozone loss rates are extremely sensitive

to the trajectories calculated, particularly for January. Therefore, uncertainties associated with loss rates in January should be substantially larger than those previously published. Integrated ozone loss in both years are comparable to those published in numerous other studies and with the results of a potential vorticity (PV)/potential temperature (Theta) approach that was employed as well. This study suggests an alternate approach to Match using trajectory mapping that more accurately reflects the true uncertainties associated with Match and reduces the dependence upon filters that may bias the results in the original Match approach, in which ~90% of matched data are rejected.

Description of Research

The Match technique has been widely applied to the problem of calculating ozone loss rates in the Arctic winter stratosphere and, just this past year, to the Antarctic. The technique relies upon the coordinated launches of multiple ozonesonde instruments from numerous stations in the Northern Hemisphere. Using a model of atmospheric dynamics, the observations can be linked by computing trajectories for the air masses in which the ozonesondes make their measurements. By examining the difference in ozone in the air mass between two "matched" ozonesonde measurements, the chemical component of ozone loss can be computed. To find the ozone loss rate, the change in ozone is simply divided by the total number of hours of sunlight illumination for the air mass between the observations. Previous publications by Rex *et al.* [1998, 2002] found rather large ozone loss rates, particularly in January 1992. Current understanding of stratospheric chemistry is unable to reproduce the loss rates reported by Match. Furthermore, the error bars associated with the loss rates in the Match papers are extremely narrow. The goals of the present study are to reproduce the Match study for the 1992 and 2000 winter seasons and to evaluate the error bars associated with the ozone loss rates produced by Match.

Accomplishments during the Reporting Period

To accomplish the goals of this task, the Match technique was first recreated. Although unable to reproduce the loss rates published by Rex *et al.* [1998] for January 1992, and with somewhat smaller loss rates in March 2000 than found by Rex *et al.* [2002], our version of Match shows good agreement with the original results for most other periods. Sensitivity studies indicate that the actual uncertainties associated with the Match ozone loss rates may be much larger than those published, especially during the January, for which the results are extremely sensitive to the amount of solar illumination and, thus, to the precise trajectory followed by each air parcel.

Sensitivity studies also indicate that the only Match filters that appear to have significant impact on the Match results are those associated with PV variability along the back trajectory and the amount of descent. For the former parameter, filtering out Matches that show more than 40% variation in PV along the calculated back trajectory is warranted. For the latter parameter, each year must be evaluated independently to determine an appropriate filtering criterion. Filtering Matches that experienced a descent of 15 K or more seemed warranted in 1992, while that filter needed to be tightened to parcels with 10 K or more of descent in 2000. Sensitivity studies further indicate that trajectories of up to 14 days can be included in Match analyses with no negative impact on the ozone loss-rate calculations. In addition, the parcel-spreading filter may be unnecessary. Parcels that have spread by up to 3000 km can be included in the Match ozone loss calculations with little negative impact on the results.

When integrating results for the SOLVE campaign, the current version of Match showed good agreement for the accumulated ozone loss with other studies over the January to March period as shown in Newman *et al.* [2002], with ozone loss somewhat smaller in magnitude than that of Rex *et al.* [2000] but still in the middle of the range of published results.

The PV/Theta approach of Lait *et al.* [2002] was applied to the 1992 data. Loss rates from the current study show excellent agreement with numerous other publications from AASE-2, including *in situ* observations and photochemical model studies.

An alternative approach to Match, the trajectory mapping approach, requires no data filtering and relies upon the large number of matches that can be obtained to compensate for the increased uncertainties associated with individual matches. While this approach produces more consistent and slowly varying average ozone loss rates, the loss rates so calculated are smaller in magnitude than those found using the original Match technique. One possible explanation is that Match selects highly localized episodes of large ozone losses. The trajectory mapping approach includes far more matches, thereby mitigating the effect of isolated events of apparently large amounts of ozone loss. The largest ozone loss rate from the original Match technique, therefore, may not be representative of conditions throughout the entire vortex simultaneously, but rather in specific locations in the vortex, as suggested by Salawitch *et al.* [1993] for ER-2 data during AASE-2.

Large ozone loss rates remain troublingly inconsistent with our current understanding of polar stratospheric chemistry [*e.g.,* Becker *et al.* 2000]. The smaller ozone loss rates found in our version of Match and in the trajectory mapping approach are more consistent with currently accepted chemistry. Although the Match studies have produced an appealing and consistent picture of high ozone loss rates associated with large areas of cold temperatures that often lead to the development of polar stratospheric clouds, the picture may not be so clear when errors are more appropriately considered. While Match truly represents a powerful approach to studying ozone loss, it must be applied with great care to produce reliable, robust results.

Objectives for the Coming Year

Plans call for completion of the current version of Match for the 1992 and 2000 winters. The Match approach will then be extended to other Arctic winters as well as to other data sets, including those from the SAGE, the Halogen Occultation Experiment (HALOE), and the Polar Ozone and Aerosol Measurement (POAM).

Task 916-04-076: **Surface UV Irradiance and Aerosol UV Absorption Remote Sensing**

GEST Investigator: Nickolay A. Krotkov

Collaborators: Jay Herman (PI, GFSC), P.K. Bhartia (GSFC)

Abstract

The focus of research under this task is the application of satellite data, such as ultraviolet (UV) irradiance estimation at the Earth's surface from the NASA Total Ozone Mapping Spectrometer (TOMS) mission and the Ozone Monitoring Instrument (OMI) on the Earth Observation System (EOS) Aura satellite, due to launch in June 2004. The focus is on satellite data validation using ground-based passive remote sensing techniques. Measurements were conducted to quantify absorbing aerosol properties in the UV as well as on direct aerosol forcing of surface UV irradiance. Radiative transfer modeling was extensively used to combine and cross-validate different methods of measuring column aerosol absorption and to ensure consistent aerosol retrievals between UV and visible wavelengths.

Description of Research

Knowledge of aerosol absorption in the near-UV is important for studies of tropospheric chemistry because it changes the rate of photochemical reactions and smog production and penetration of biologically harmful UV radiation to the Earth's surface. Research focused on extending ground-based passive measurements of column aerosol absorption into the UV spectral region. The goals of this work are to validate TOMS and future Aura/OMI aerosol absorption products; to measure aerosol absorption consistently across UV and visible wavelengths; to distinguish between absorption by black carbon and other potential UV absorbers (*e.g.,* organics and nitrated and aromatic aerosols and gases); and to predict aerosol effects on photolysis frequency rates and surface UV irradiance.

Accomplishments during the Reporting Period

The TOMS surface UV irradiance database (which covers the period 1978 - 2003) was expanded to include five new products (noon irradiance at 305, 310, 324, and 380 nm, and noon erythemal-weighted irradiance), in addition to the existing erythemal daily exposure, which permits direct comparisons with ground-based measurements from UV spectrometers. The comparisons were used to quantify biases between TOMS UV estimates and ground-based measurements of surface UV irradiance. Sensitivity studies were conducted to quantify uncertainties of the TOMS UV irradiance data due to *a priori* algorithm assumptions.

Summertime clear-sky positive bias between TOMS UV estimations and ground-based Brewer spectrometer measurements was found at non-ozone-absorbing wavelengths. This suggests that the uncertainty of UV aerosol absorption properties is a major source of error in modeling surface UV irradiance under clear-sky conditions. Although absorption effects of dust and elevated carbonaceous aerosols are already accounted for using the TOMS Aerosol Index (AI) technique, sensitivity studies revealed that absorption properties of pollution aerosols in the planetary boundary layer (PBL) remain uncorrected, which results in a positive summertime bias in TOMS UV estimations over many locations. Due to high aerosol variability, the bias is strongly site dependent. Data from UV-shadow-band radiometers and well-calibrated CIMEL sun-sky radiometers were analyzed to quantify the aerosol absorption bias at GSFC in Greenbelt, MD, which is representative of a larger mid-Atlantic urbanized area. This work involves scientists from GSFC and the U.S. Department of Agriculture UV-B network. The additional absorbing aerosol correction based on new TOMS aerosol absorption data was developed and shown to improve TOMS UV comparisons with ground-based spectral UV measurements.

A modeling study was conducted to clarify the effect of clouds on measured TOMS UV backscattered radiances and ozone retrieval. The study confirmed that current cloud lookup tables—based on plane parallel homogeneous cloud models with C1 droplet size distribution—are adequate to describe average cloud reflectance from low-resolution TOMS and OMI data, and cloud spectral signatures in the UV region. Therefore, no additional cloud-related bias is expected for satellite column ozone and surface UV irradiance data.

A wintertime bias was also found in the TOMS UV data due to an inability to distinguish between snow and cloud cover using only TOMS UV reflectance data. This results in large errors in estimating surface UV using snow climatology. A correction was suggested for the case when the regional snow albedo is known from an independent source.

Objectives for the Coming Year

Ground-based passive remote sensing of column aerosol absorption across the UV-visible spectral range will continue at the GSFC site using a combination of direct sun sky radiance, and total and diffuse irradiance measurements. Comparisons with standard Aerosol Robotic Network (AERONET) inversions will be conducted. The use of the new TOMS long-term global data record of UV aerosol absorption optical thickness is expected to improve the accuracy of TOMS spectral UV products by properly including the spectral attenuation effects of carbonaceous, urban/industrial, and mineral aerosols. The TOMS data set of aerosol properties will be used, and results of such use in the TOMS and OMI surface UV algorithm will be analyzed. Finally, with the expected launch of the EOS Aura satellite in June 2004, radiances, aerosols, and surface UV irradiance data will be analyzed and validated.

Task 916-13-121: **Climate and Trace Species**

GEST Investigator: Eric Bucsela

Collaborators: James Gleason (PI, GSFC), Edward Celarier (SGI/GSFC), Mark Wenig (GSFC), P.K. Bhartia (GSFC), Ernie Hilsenrath (GSFC), Scott Janz (GSFC), George Mount (Washington State University), Randall Martin (Dalhousie University)

Abstract

Progress was made in developing the NO_2 algorithm that will be used to process data from the Ozone Monitoring Instrument (OMI) on the Earth Observing System (EOS) Aura platform, scheduled for launch in June 2004. Extensive systematic investigations of the algorithm were carried out using both simulated and actual data from the European Space Agency's Global Ozone Monitoring Experiment (GOME) instrument. The studies used air mass factors derived from the TOMRAD radiative transfer model developed at NASA, and tropospheric profile estimates from the Goddard Earth Observing System (GEOS)-CHEM model at Harvard University. Further simulations of OMI data were obtained from NASA's chemistry and transport model (CTM), which estimates stratospheric NO_2. These data were critical in optimizing the algorithm, and investigations with the data showed the need for significant modifications of the parameters used in the algorithm. The optimized algorithm was used to infer better NO_2 columns from previously analyzed GOME measurements. Work began on a newly funded, ground-based study of NO_2, in collaboration with researchers at Washington State University.

Description of Research

The principal objective of the past year's research was to support trace-gas-retrieval for the EOS Aura mission. Work focused on developing algorithms for NO_2 retrievals from the OMI instrument, and on ground-based validation programs. The goal was to build on feasibility studies from the previous year that looked at issues including air mass factor estimations, cloud cover sensitivities, and tropospheric/stratospheric separation schemes. This work will be implemented in the code written to process actual OMI data and existing data sets obtained with the GOME instrument. The air mass factor studies were also useful in planning the ground-based investigations.

Accomplishments during the Reporting Period

Final refinements were implemented in trace-gas retrieval algorithms in preparation for the upcoming deployment of the EOS Aura satellite, with specific attention paid to data from the OMI, which, in addition to ozone, will be able to measure column amounts of NO_2. Work on the OMI instrument is being carried out at NASA as part of a joint venture with the Royal Netherlands Meteorological Institute (KNMI). Significant milestones for the year included delivery of updated versions of the NO_2 algorithms to the Science Investigator-led Processing System (SIPS) processor at GSFC, and algorithm testing using synthetic data from KNMI.

The GSFC team investigated the ways in which global NO_2 can be measured from satellites; the findings were implemented in the OMI algorithm. A hallmark of the method is that it relies on model input as little as possible. Since NO_2 profiles, which are needed to compute air mass factors (AMFs), are not known *a priori,* some estimate of these profile shapes is needed to process the satellite observations. Although existing methods [*e.g.,* Martin *et al.* 2002] often use models to estimate these profiles at each observation time and for each point on the Earth, the method used in the OMI algorithm seeks to use a smaller number of representative profiles—one for the stratosphere and an average set for the troposphere—for the analysis. An accomplishment of this year's study was the development of a way to optimize profile choice, and to show that a very small number of profiles can yield NO_2 vertical column densities (VCDs) consistent with the nominal uncertainty for the retrievals.

An important development in optimizing and quantifying uncertainty in the OMI algorithm was the use of stratospheric model information to test the algorithm. Such information is useful for algorithm testing because the test results can be compared with known inputs to assess retrieval accuracy. The method that will be used to process the OMI NO_2 data relies on the assumption of relative spatial homogeneity of the stratospheric NO_2 field to identify the smaller-scale variations in tropospheric NO_2 distribution. Stratospheric NO_2 column amounts from the CTM were combined with tropospheric columns from the Harvard GEOS-CHEM model to produce simulated data fields. Analysis of these fields was used to optimize retrieval parameters in the OMI algorithm. Although the stratospheric variation in the NO_2 fields was somewhat greater than expected, optimal parameters (*e.g.,* tropospheric masking and stratospheric smoothing parameters) were obtained, and found to give acceptable accuracy in the retrieved VCDs.

Further understanding of AMFs was also gained during the past year. The effects of terrain and cloud height on the differential (or altitude-dependent) air mass factors (dAMFs) and the small influence of absolute number density (rather than just profile-shape) were quantified. These effects are most pronounced in polluted regions, which contain large amounts of tropospheric NO_2. The AMFs were implemented in the OMI NO_2 algorithm and applied to GOME data. As expected, significant enhancements in vertical column densities (VCDs) were seen in polluted regions, relative to the VCDs obtained when only stratospheric AMFs were used. However, analysis of the GOME data also revealed that application of AMF to convert slant to vertical columns could lead to potentially unrealistic vertical column densities in polluted cloudy regions. This observation may lead to reanalysis of AMFs under partly cloudy to cloudy conditions and algorithm improvements with respect to the detection and correction of polluted NO_2.

Some of the work on NO_2 slant column retrievals and their conversion to vertical column amounts was also applied in the study for a proposed OMI validation experiment. A new, to-be-developed instrument, a ground-based Multi-axis Differential Optical Absorption Spectrometer (MAX-DOAS), will measure NO_2 column densities at a specific site and compare them to concurrent OMI measurements from the Aura satellite. The plan is to use DOAS-type spectral retrievals at several viewing geometries to determine the tropospheric component of the NO_2 vertical column density. This component will be identified by comparing slant columns at low and high ground-based viewing zenith angles. Significant progress was made in determining specifics of the instrument's construction and in plans for the processing of the data.

Objectives for the Coming Year

Members of the OMI trace-gas retrieval team will focus on continued development of the OMI operational algorithm and on the validation campaign. The operational algorithm will be ready for use after launch, but will continue to undergo testing to improve retrieval capabilities. Some of these tests will involve synthetic data, as during the past year. A large part of OMI-related work will involve MAX-DOAS construction and algorithm development, which will require extensive calculations using radiative transfer codes to optimize hardware design and retrieval parameters to effectively measure tropospheric NO_2, with minimal dependence on specific knowledge of NO_2 profile shape or spatial inhomogeneities.

Task 916-21-144 and Task 916-43-181: **Tropospheric Ozone Derived From Satellite Measurements**

GEST Investigator: Jerry R. Ziemke and Sushil Chandra (respectively)

Collaborators: P. K. Bhartia (PI, GSFC), Changwoo Ahn (SSAI)

Abstract

During the reporting period efforts continued in developing and maintaining satellite-derived data sets of tropospheric column ozone (TCO) and stratospheric column ozone (SCO) for 1979-present. These ozone data products are obtained from the Total Ozone Mapping Spectrometer (TOMS) ozone measurements using the Convective Cloud Differential (CCD) method. Two important new algorithms developed under this joint task are the Cloud Slicing (a generalization of the CCD method) and cross-calibration residual methods. Cloud slicing derives tropospheric ozone profile information, and the cross-calibration residual method (which uses CCD SCO) provides global measurements of TCO. Aside from the development of public domain data products for NASA, the investigators research, which combines measurements and photochemical transport models, has led to substantial new understanding of the dynamics and sources and sinks of tropospheric ozone. These studies have led to new and important discoveries in measured tropospheric ozone in relation to intraseasonal and interannual variabilities associated with the one-to-two-month Madden Julian Oscillation (MJO), and La Niña and El Niño events.

Description of Research

The primary purpose of these joint tasks is to derive tropospheric ozone data products from satellite-based ozone measurements. In addition to developing tropospheric ozone data products for NASA, a significant amount of scientific research is conducted in an effort to understand the nature of these observations. This includes the use of photochemical transport models (*e.g.,* MOZART-2, GEOS-CHEM) to quantify the various factors contributing to the observed ozone characteristics. The work involves developing scientific retrieval algorithms, validating the derived data products with ground-based ozonesonde measurements, and conducting scientific research with the ozone data, including model comparisons. The work is devoted primarily to using existing TOMS ozone data (1979-present) to develop tropospheric ozone algorithms and to derive additional data. Efforts in the near future will use these same concepts to derive tropospheric ozone data products from the Earth Observing System (EOS) Aura satellite, scheduled for launch in June 2004.

Accomplishments during the Reporting Period

Public domain data were established for tropospheric and stratospheric ozone derived from Cloud Slicing and TOMS/Microwave Limb Sounder (MLS) residual methods. Intraseasonal, interannual, and decadal changes in TCO, associated with the Madden-Julian Oscillation (MJO), Quasi-Biennial Oscillation (QBO), El Niño and La Niña events, and solar cycle were characterized. The relative importance of dynamics and chemistry in the tropical region were studied, with special reference to the El Niño of 1997-1998. The effects of pollution on tropospheric ozone in mid-latitudes were studied by comparing the TOMS satellite measurements with global models (*e.g.,* MOZART-2, GEOS-CHEM).

Objectives for the Coming Year

In the coming year, the Cloud Slicing and TOMS/MLS TCO public domain data products will be updated with new (version 8) TOMS measurements. These will be validated with Southern Hemisphere Additional Ozonesondes (SHADOZ) and World Ozone and UV Radiation Data Center (WOUDC) data. Daily global tropospheric ozone from TOMS will be developed to characterize pollution events and to further study intraseasonal oscillations such as the one-to-two-month MJO for the period 1979-present. TOMS CCD SCO, MLS and SAGE SCO, ozonesonde, and geophysical meteorological data will be combined to develop methods to derive

daily stratospheric column ozone from SBUV profile data. TCO will then be obtained by subtracting these amounts from TOMS total column ozone for 1979-present. The working algorithms will be used in the near future for deriving TCO and SCO data products from the EOS Aura platform. The analysis of the MOZART-2 model will continue to delineate the relative importance of surface NO_x emission, lightning NOx emission, and stratospheric influx, which all contribute in unique ways to the spatial and temporal variability observed in TCO derived from satellite measurements.

Task 916-37-173: **Stratosphere-Troposphere Exchange**

GEST Investigator: Mark A. Olsen

Collaborators: Anne R. Douglass (PI, GSFC), Mark R. Schoeberl (GSFC)

Abstract

Research has shown that more midlatitude cross-tropopause ozone transport occurs in the Northern Hemisphere (NH) than the Southern Hemisphere (SH), due primarily to greater ozone concentrations—not dynamical differences—near the NH midlatitude tropopause. A study comparing the tropopause flux of mass and ozone shows that the mass and ozone seasonal cycles are shifted by about one month. The diabatic ozone fluxes show that ozone concentrations near the SH tropopause are significantly altered from blocking of meridional transport by the SH stratospheric vortex. The downward diabatic flux of mass and ozone in both hemispheres is concentrated at midlatitudes, while a significant net upward adiabatic mass flux exists at higher latitudes. Research on the amount of water vapor transported from the Asian monsoon to the tropical stratosphere has led to testing and refinement of a new adjoint version of the Goddard Parameterized Chemistry and Transport Model (GPCTM).

Description of Research

The exchange of air and chemical species across the tropopause has implications for many atmospheric chemistry and climate problems. In addition, the tropopause region significantly influences atmospheric radiative properties. Thus, it is important for research models to accurately represent stratosphere-troposphere exchange (STE). This research focuses on the analysis of STE in global atmospheric data sets and model output. Science issues addressed include ozone trends in the upper-troposphere/lower-stratosphere; seasonal and interannual trends in total mass and ozone STE; and the importance of STE to climate change.

Accomplishments during the Reporting Period

A new method to evaluate extratropical mass exchange was used to compare the STE of ozone in the Northern Hemisphere (NH) and Southern Hemisphere (SH). The diagnostic algorithm uses trajectory-based reverse domain filling, combined with an empirical column ozone-potential vorticity (PV) relationship to examine the flux of ozone across a PV-defined tropopause. This method is both useful and unique in that it can be applied to a wide range of spatial and temporal scales. *Olsen et al.* [2003] show that the algorithm is effective in separating the dynamical aspects of transport from the seasonal cycle of ozone in the lowest portions of the stratosphere. These results illustrate that the greater ozone flux at NH midlatitudes (30° - 60°) is due primarily to the amount of ozone available for exchange rather than dynamical differences near the tropopause level at these latitudes. The greater ozone concentrations are ultimately due to greater stratospheric wave driving in the NH.

A continuous 50-year integration of the Goddard 3-D Chemistry and Transport Model (CTM) has been completed. An evaluation and comparison of the cross-tropopause fluxes of air mass and ozone for the first few years of results have been completed. The method used for this study calculates both the total and diabatic extratropical mass and ozone STE; the difference of these determines the adiabatic flux. The phases of the mass and ozone flux annual cycles are offset since

the dynamical transport seasonal cycle is phase-shifted with respect to the ozone concentration. This study also found that the seasonality of the upper-troposphere/lower-stratosphere ozone mixing ratio and STE is strikingly different between the NH and SH at high latitudes. This is caused by the stronger SH stratospheric vortex, which more effectively blocks meridional transport than its NH counterpart. As a result, the net diabatic fluxes of ozone in the NH and SH are temporally in phase and not offset by six months, as was expected from seasonal considerations alone. The study also showed that a relatively large amount of mass is transported adiabatically into the stratosphere from the troposphere at high latitudes. The net diabatic transport is from the stratosphere into the troposphere, and is concentrated at midlatitudes along climatological storm tracks. Thus, a mid- and high-latitude mean meridional circulation must exist. This would create a much longer timescale "transient" flux (*i.e.,* stratosphere to troposphere, and back again) than previously investigated. Finally, differences between the adiabatic and diabatic ozone fluxes suggest that the pathways of cross-tropopause transport are generally distinct. These pathways can be characterized as being adiabatic or diabatic, but are less likely to be a combination of the two.

A study to determine the influence the Asian monsoon has on the tropical stratospheric water vapor was initiated during the past year. Initial results were obtained using traditional Lagrangian trajectory analysis. They showed that the monsoon circulation might play a significant role in modulating the seasonal water vapor signal. However, the trajectory analysis is not ideal for determining the amount of mass transported, since the parcels are nondiffusive and nonmixing. In support of this research, the GEST investigator has assumed the lead at GSFC on developing and testing a new adjoint version of the GPCTM. Scientists at the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR) are also involved. An Eulerian approach is both ideal and unique for such studies. The model still requires further refinement and testing for research use, although should be usable by the middle of 2004. The adjoint model will provide new and unique opportunities for evaluating STE, and will be useful for other research topics, such as constraining model sources and sinks of carbon.

Objectives for the Coming Year

Work in the upcoming year will focus on two areas. The 50-year CTM integration will enable examination of long-term trends in mass and ozone STE; spatial and temporal distribution trends as well as magnitude will be investigated. In addition to the magnitude, the distributions are of great importance to tropospheric chemistry and climate change issues. The mechanisms of cross-tropopause transport will be examined in more detail by determining both the adiabatic and diabatic magnitudes and distributions. Other research will continue to examine the influence of the Asian monsoon on tropical stratospheric water vapor. Initial Eulerian studies will use the forward-running PCTM to provide information on the pathways of transport from the monsoon region to the tropical stratosphere. This information will be used to guide the adjoint model investigations when the model development and validation is completed.

Task 916-39-176: **Design and Implementation of a Common Chemistry and Transport Model Framework for the Interactive Simulation of Stratospheric and Tropospheric Photochemical Systems**

GEST Investigator: Huisheng Bian

Collaborators: Randy Kawa (PI, GSFC), Mian Chin (GSFC)

Abstract

The capability of studying both tropospheric and stratospheric photochemistry in a consistent way using broadly available chemistry and transport models (CTMs) is a critical need to improve our understanding of atmospheric chemistry and the

climate system. A new initiative has been organized in GSFC's Atmospheric Chemistry and Dynamics Branch (Code 916) to move their efforts in this direction. The study described here has established a common CTM framework, including all dynamical processes required for future chemistry model development. This model framework is concise in structure, efficient in data management, user friendly in model application, and easily upgraded.

Description of Research

The Atmospheric Chemistry and Dynamics Branch modeling group is developing a CTM system that couples stratospheric and tropospheric photochemical processes. This effort builds upon experience gained from satellite remote sensing of the stratosphere, and is in response to the emergence of new satellite remote sensing measurements of the troposphere. The new models will enhance our ability to address important scientific issues, such as future recovery of stratospheric ozone, the interaction of ongoing climate change and atmospheric chemistry composition, and the response of regional-global air quality. This effort challenges computational technology due to the high spatial and temporal resolution required in the troposphere and the coupling of tropospheric and stratospheric domains. Recent advances in the development of new chemistry solver algorithms and in computational resources provide the tools needed by the modeling group to reach this challenging goal.

Accomplishments during the Reporting Period

This newly initiated model development activity is expected to provide the foundation for future research focused on chemical and dynamical processes in the Earth's atmosphere. The first major accomplished during this period was the design and implementation of the common CTM framework into a model (temporarily identified as the "UCTM") needed to accommodate future developments in complex chemistry modules. The new model includes all dynamical processes and is concise in structure, efficient in data management, "user friendly" in model application, and is easily upgraded.

Objectives for the Coming Year

In the coming year the newly developed UCTM will be used in scientific studies. Based on an analysis of the results of these scientific applications, improvements will be made to the UCTM design. Comprehensive documentation will be developed and provided to potential users. Parallel calculations will be implemented to increase the model's calculation speed. The first scientific application of the UCTM will be to provide understanding and interpretation of satellite-derived, high-spatial-resolution carbon dioxide measurements. The radiative and microphysical properties of atmospheric aerosols will also be implemented in the UCTM during the coming year. Aerosol properties to be addressed include source emission rate, dry and wet depositions, dynamical transport, and radiative properties for use in calculations of radiative forcing. With the inclusion of interactive atmospheric aerosols UCTM will be used to investigate radiative forcing by black carbon aerosols. Earlier studies showed that black carbon is the only aerosol species with a significant positive radiative forcing in our atmosphere. Elucidation of the radiative forcing due to black carbon aerosols and their interaction with other atmospheric processes may make a significant contribution to our understanding of global climate change.

NASA Grants: **Solar Irradiance Variability and Climate Implications (NAG5-11326, NAG5-11601, NAG5-11624)**

GEST Investigator: Judit M. Pap

Collaborators: Stuart Jordan (GSFC), Charles Jackman (GSFC), Doug Rabin (GSFC), Harry Jones (GSFC), William Thomas (GSFC)

Abstract

The objectives and results of three grant-funded investigations addressing the phenomenon of solar variability and its connection to climate change are outlined in this report. The first investigation focuses on developing an understanding of the relationship between variations in solar irradiance (both bolometric and at various ultraviolet and extended ultraviolet wavelengths) and the magnetic fields of active solar regions (sunspots and faculae) as measured by the Solar and Heliospheric Observatory (SOHO)/Michelson Doppler Imager (MDI) satellite-based experiment, and full-disk magnetic field strength data, as measured at the Kitt Peak Solar Observatory. A second investigation involved reprocessing total solar irradiance measurements from the Upper Atmosphere Research Satellite (UARS)/Active Cavity Radiometer Irradiance Monitor (ACRIM) II. Currently, these reprocessed data are being validated and integrated into the long-term NASA irradiance database. A third investigation was initiated during the reporting period to better understand the physical mechanisms underlying the connection between solar irradiance variability and climate change.

Description of Research

This research studies variations in solar output using observations from various surface and space-based sources, such as the Kitt Peak magnetic field observations, images from the Precision Solar Photometric Telescopes (PSPT), SOHO/MDI, and the Variability Irradiance and Gravity Oscillations (VIRGO) and Solar Extreme Ultraviolet Monitor (SEM) experiments on SOHO. To analyze these data obtained from ground- and space-based assets, state-of-the-art image and time series analysis techniques are used. Results serve to characterize variations in solar output—examining the links between different indices—and to understand the reasons for the variations. The ultimate goal is to understand the physical origin of irradiance variations to reconstruct and predict solar-induced climate changes. The work includes leading several international efforts and collaboration with scientists from different organizations.

Accomplishments during the Reporting Period

During the last year, task work continued to study the origin of solar irradiance variations. Results show that both total irradiance (integrated over the entire solar spectrum) and UV irradiance increased more during the weak solar cycle 23 than the rest of the magnetic indices. Photometric results indicate that, in general, during solar cycle 23 fewer and smaller sunspots occurred, except for a few high-activity outbursts. Although the diminution in sunspot darkening would explain the high total irradiance values during the weak cycle 23, it cannot explain the high UV irradiance values, indicating that other physical processes are present. To further study this problem, analysis of the high resolution MDI images started during the PI's work at the Jet Propulsion Laboratory (JPL), where it was found that using magnetic field and intensity values to identify sunspots and faculae for the time interval that included the maximum of cycle 23 may separate the strong facular fields from the weaker network fields. Further studies on this topic are in progress. These results may have climatological significance, since irradiance models used in current climate studies assume that there is a linear relation between irradiance variations and magnetic activity as represented either by the area or number of sunspots.

As part of the same study, the so-called Photometric Sunspot Index (PSI) from MDI images was compared with the currently used PSI indices. Our results show that the MDI sunspot areas are systematically larger than published PSI indices; this factor must be taken into account in

future irradiance models. Comparison of the MDI faculae areas with UV irradiance data, as represented with the magnesium core-to-wing ratio, shows that chromospheric UV irradiance is well-correlated facular magnetic fields. This result confirms that our classification of faculae is properly performed. However, it also indicates that UV irradiance variations are mainly governed by changes in magnetic fields.

During the last year, the PI addressed the controversial question of whether total irradiance was higher during the minimum of cycle 21 than during the minimum of cycle 22. It was found that the declining trend in the Earth Radiation Budget

Satellite (ERBS) total irradiance during solar minimum is related to the effect of sunspots. The relationship between various total irradiance data was studied in detail, and a new factor adjusting the ACRIM I data to the ACRIM II level was calculated. These results show that total irradiance may indeed be somewhat higher during the minimum of cycle 22 than during cycle 21; however, the difference is within the current measurement accuracy.

Objectives for the Coming Year

The key objective for the coming year is to continue the intercomparison of various total solar irradiance data sets and to improve the currently available composite. As part of this research, the PI will compare the SOHO/VIRGO and ACRIMSAT total irradiance. The Solar Radiance and Climate Experiment (SORCE) total irradiance will be part of this study as soon as the data become publicly available. This work is a collaborative effort with Dr. Claus Frohlich, VIRGO PI, and Dr. R.C. Willson, ACRIMSAT PI.

An additional goal is to study solar extreme UV irradiance variability, with emphasis on the rapid variations related to solar flares. The main goal is to study the structure, evolution, and magnetic configuration of sunspots, and to develop a method (based on these statistics) to predict solar flares and their effect on the Earth's atmosphere. In addition to the MDI data, plans call for including results produced by the Global Oscillations Network Group (GONG) and the newly implemented Synoptic Optical Long-term Investigations of the Sun (SOLIS) instrument at Kitt Peak. This research is a collaborative effort with Dr. B. Tsurutani and Dr. M. Turmon of JPL. In addition, the PSPT data produced in Rome will be used. This project is an important part of the forthcoming Solar Dynamics Observatory's two experiments, providing results and analysis tools. The PI will also study (in collaboration with Dr. W. Thompson of GSFC) the relationship between strong corona lines and EUV variations to better understand the variation of the EUV irradiance in the 5-50 nm spectral range. This study is especially important since this range includes the strong spectral line at 30.4 nm that is the primary cause of the formation of the Earth's ionosphere.

Using UV irradiance data currently available from UARS, the PI will work together with Dr. K. Coughlin of the University of Washington to study the effect of UV irradiance variations on atmospheric constituents. This research will include improving some statistical techniques and combining the results gained by Singular Spectrum Analysis and the Empirical Decomposition Method.

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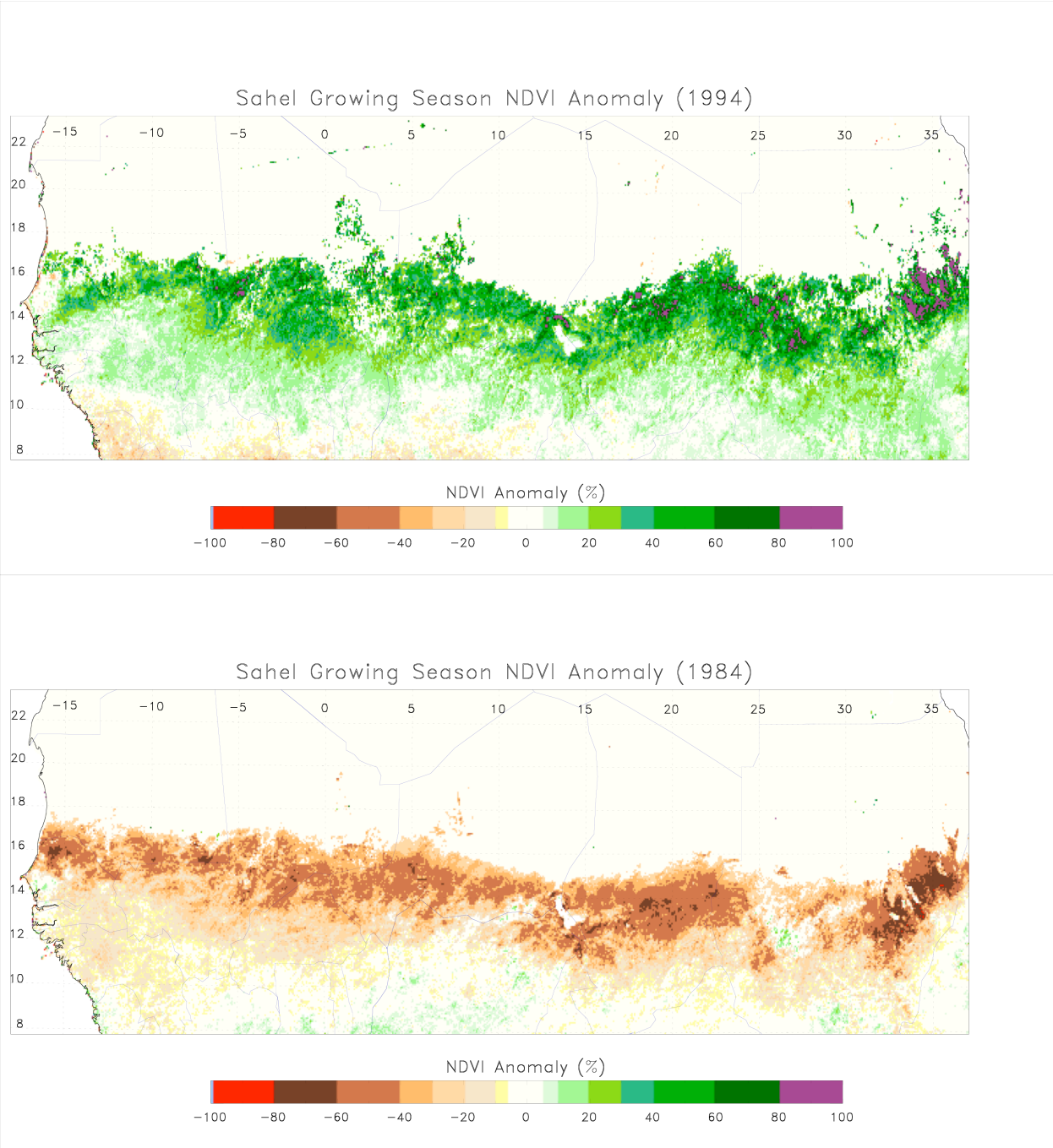
Terrestrial Physics Research Group



Growing season (July – October) normalized difference vegetation index (NDVI) anomaly patterns for the Sahel region. Region-wide drought during the 1984 season (top) compared to above-normal NDVI during the 1994 growing season (bottom). Anomalies are calculated as percent departures from 1982-1999 mean (Source: Anyamba. A. and C. J. Tucker, Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981-2003*, Journal of Arid Lands, in review 2004).*

Figure provided by Assaf Anyamba

Terrestrial Physics Research Group

The GEST Terrestrial Physics Research Group consists of eighteen researchers whose interests integrate geospheric, hydrospheric, and biospheric aspects of the remote sensing of the Earth. The group not only studies a wide variety of science processes, but also spans the entire development and implementation lifecycle of remote sensing technologies. One subgroup is interested in optimizing the sensor and algorithm capabilities of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP), which is a mission to bridge the gap from Earth Observing System (EOS)-era missions to future capabilities. A second subgroup is developing the Aerosol Robotic Network (AERONET) capability to provide ground-based validation assets and to develop new algorithms for various climatic, weather forecasting, and tactical applications. The work performed in this group can feed back into developmental processes for the next generation of Earth observation technologies, and lay the foundation for long-term, consistent data sets that are the basis of climate research applications. A third subgroup of GEST researchers is investigating a diverse set of physical processes linked to climate change research, using years of data over wide geographical areas. Through close collaboration with NASA and other research and operational agencies, the process of interpretation, modeling, and assimilation will lead to improved system-wide science understanding and improved remote sensing technologies that provide the foundation on which the science activities are built.

The NPOESS is the next generation of remote sensing platforms, designed to replace and combine the present military Defense Meteorological Satellite Program (DMSP) and the National Oceanic and Atmospheric Administration (NOAA) polar system. The NPP, presently scheduled for launch at the end of 2006, will span the temporal gap between the end of the EOS missions and the start of NPOESS operations. Several researchers are addressing sensor and system development within the NPP and NPOESS framework. Dr. Guenther is chiefly concerned with calibration and validation of the four NPP sensors, while Dr. Kealy works on algorithm design and implementation into the real-time operational system. Drs. Lyapustin, Wang, and Nirala are exploring algorithm improvements with potential for insertion into the program. This algorithm will provide surface temperature and internally consistent aerosol retrievals and atmospheric correction. The algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects and gaseous absorption in the atmosphere. The atmospheric correction algorithm will be validated with data from AERONET.

The AERONET efforts cover research by Drs. Dubovik, Eck, Gatebe, O'Neill, and Smirnov. These efforts focus on the deployment, validation, and analysis of measurements made by automatic sun-sky scanning radiometers. Additional AERONET sites were deployed and algorithm improvements derived in several areas. Advances were made in developing and validating an algorithm for the spectral separation of coarse- and fine-mode contributions to aerosol optical depth. The effects of variation in the angular distribution of light, its polarization characteristics, and algorithm performance in maritime and smoky environments also led to improvements in understanding aerosols and their effect on climate. Dr. Gassó is conducting additional aerosol work, with an emphasis on aerosol interaction with clouds. This work, in collaboration with the Navy, also utilizes sunphotometers and *in situ* platforms to validate the algorithm.

The processes of algorithm development and validation merge into large-scale data analysis over global and continental scales. Dr. Cohen's research interest for example, uses Landsat data in intensive study areas to support continental-scale research into forest disturbance effects across the North American continent. Similarly, Dr. Margolis is using ground measurements in combination with EOS Moderate Resolution Imaging Spectroradiometer (MODIS) data to study forest ecosystem dynamics under the auspices of the North American Carbon Program (NACP). The African continent is the major focus of Dr. Anyamba, who is studying the El Niño/Southern Oscillation (ENSO) effect on vegetation and fire patterns using data from the NOAA Advanced Very High Resolution Radiometer (AVHRR). A further

regional study, conducted by Dr. Yurchak, investigates the combination of remote sensing technologies, geographic information systems (GIS), and local, ground-based knowledge to manage information that addresses the reindeer population of Arctic regions.

In addition to the meteorological and biophysical aspects of terrestrial applications, this group also studies regional and global gravity and magnetic affects. These studies link ground measurements to satellite missions. Dr. Hinderer's research focus is on gravity measurements to gain better insight into long-term global geodynamics, while Dr. Kim is concerned with magnetic anomalies, particularly in the Antarctic. Many of the gravity and magnetic techniques used here are being applied to Martian studies.
Dr. Sakimoto's research covers a wide range of planetary geology, geophysics, and terrestrial physical volcanology objectives that are important for understanding planetary surface processes such as volcanism, cratering, and surface water flow on Earth and Mars.

This summary and this year's impressive publication and presentation record this year show the group's research interests, which cover not only a variety of high-level terrestrial physics applications, but which also span the full development cycle of remote sensing technologies.

Peter Merheim-Kealy

Task 900-03-041: **Spectral, Angular, and Vertical Characterization of Aerosols for Radiative Properties**

GEST Investigator: Charles K. Gatebe

Collaborators: Michael D. King (PI, GSFC), Oleg Dubovik (GEST)

Abstract

This past year was marked by the completion of a new algorithm for inverting combined Cloud Absorption Radiometer (CAR) and Aerosol Robotic Network (AERONET) multispectral and multiangular radiance measurements. This involved modifying the AERONET computer code to derive aerosol information from measurements of sun/sky radiance. In particular, the new algorithm was adapted to the CAR geometry and spectral range to include a description of the surface bidirectional reflectance function (BDRF) properties at one or several vertical levels. These modifications have enabled simultaneous retrieval of detailed surface properties and complete optical properties of aerosols above and below the aircraft at discrete spectral wavelengths in the ultraviolet, visible, and near-infrared regions of the solar spectrum. Sensitivity tests illustrating the potential of the combined CAR and AERONET retrievals, together with applications of the real data, have been successful.

Description of Research

This study seeks to characterize aerosol radiative properties using multispectral and multiangular radiation field measurements. This involves detailed assessment of the CAR data from selected field campaigns. This effort is tied to the development of a new algorithm for inverting CAR multispectral and multiangular radiance measurements by modifying the AERONET inversion code of sun/sky radiance. In particular, the AERONET algorithm is adapted to the CAR geometry and spectral range to include a description of the surface bidirectional reflectance function properties at one or several vertical levels. The modification enables simultaneous retrieval of detailed surface and vertical variations of complete optical aerosol properties at discrete spectral wavelengths in the ultraviolet, visible, and near-infrared regions of the solar electromagnetic spectrum. Other work includes testing and validating the new algorithm to derive different types of aerosols from oil fire smoke, mineral dust, oceans, biomass burning, and industrial emissions. The main test data is drawn from the CAR multispectral and directional measurements made during the following campaigns: Kuwait Oil Fire and Smoke Experiment (KOFSE, May–June 1991); Smoke, Clouds and Radiation Experiment in Brazil (SCAR-B, August–September 1995); Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX, July 1996); Southern African Regional Science Initiative 2000 (SAFARI 2000, August–September 2000); and the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS, July-August 2001). Yet other work involves comparing collocated surface-based measurements with the surface measurements from AERONET, airborne measurements with CAR, and satellite measurements using the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Total Ozone Mapping Spectrometer (TOMS).

Accomplishments during the Reporting Period

One major effort during the reporting period was completion of a new algorithm for inverting combined CAR and AERONET multispectral and multiangular radiance measurements. This involved modifying the AERONET inversion code for deriving sun/sky radiance. Results of sensitivity tests and using real measurements illustrated the potential of combined CAR and ARONET data.

Considerable effort was devoted to developing a well-calibrated and atmospherically corrected dataset that deals with the bidirectional reflectance characteristics of the ocean. The study shows full bidirectional reflectance of the sun glint, and the water-leaving reflectance under different illumination conditions with solar zenith angles ranging from 15°-46° and wind speed from

1-11 ms^{-1}. Because of the high resolution of CAR angular (1°) and spatial (better than 4 m at nadir) measurements, coupled with high signal-to-noise and small quantization interval (16 bits), the radiance field above the ocean is seen in unprecedented detail. The widely used Cox-Munk model for predicting surface slope statistics as a function of wind speed over the ocean was validated in the study under the specific measurement conditions. Results of the validation show that although the model reproduces the shape of sun glint with an accuracy of better than 30%, it underestimates the center of the glint reflectance by about 30% for low wind speeds (<2-3 ms^{-1}). In cases of high wind speed, the model with Gram-Charlier expansion seems to provide the best fit.

Objectives for the Coming Year

Using the new inversion algorithm described above, plans call for retrievals of the columnar aerosol size distribution, effective radius, and surface area and volume distribution, using CAR transmission spectra. The optical thickness spectra and retrieved products will be used for comparisons to products from surface measurements from AERONET instruments. Since the project involves data from different geographical regions, the investigators will use the new algorithm to characterize differences between aerosols from the four regions. Particular emphasis will be placed on quantifying the wavelength- and humidity-dependent single scattering albedo of realistic multicomponent aerosols, since this parameter is so important in determining aerosol radiative impacts on climate, including top-of-atmosphere forcing, surface forcing, stability changes, and cloud changes. The effects of shape on scattering phase functions will also be investigated, including characteristic shape changes that occur during downwind evolution.

The investigators will combine the algorithms developed in this proposal with CAR data acquired while underflying plumes and hazes in downwind and crosswind transects to study how aerosol sizes and masses evolve during downwind transport, and how various sources contribute to regional mass budgets. Efforts will be made to use airborne sunphotometer water vapor measurements to estimate the condensed water content of overlying aerosols, and thereby assess the most appropriate aerosol optical property models to use in retrieving size distribution and mass for a particular type of aerosol. The CAR data will be used to assess the degree of variability within satellite pixels that may be particularly important near localized sources like small biomass fires or for measurements in broken cloud fields. Aerosol models assumed in the satellite retrievals will be compared to the aerosol models developed in this investigation, and also to aerosol properties determined from *in situ* measurements. Where significant differences in assumed and actual aerosol properties are found, examples of adjusted satellite products will be produced using the single scattering albedo and phase function of the actual aerosols. Possible shape effects for soil dust and industrial aerosols will be investigated, as will the effects of vertical distribution of absorbing and nonabsorbing aerosols. Implications of these studies will be investigated not only for atmospheric products (*e.g.,* aerosols), but also for ocean color and land surface products affected by atmospheric corrections.

Task 900-35-168: **Remote Sensing Information Support for Public Health Issues in the Arctic**

GEST Investigator: Boris S. Yurchak

Collaborators: Nancy G. Maynard (PI, GSFC), Rita L. Aissi-Wespi (DSTI)

Abstract

Public health issues in the Arctic are tightly connected with the status of reindeer husbandry. With the acceptance of the "Reindeer Mapper" concept into the Land Cover-Land Use Change Program, contacts with potential Russian collaborators and representatives of the World Reindeer Herders Association were established.

The pilot region for testing applications of remote sensing to reindeer husbandry problems was selected. Additional software was developed for data processing. A proposal was funded by NASA HQ to acquire appropriate Synthetic Aperture Radar (SAR) data from the Alaska Satellite Facility (ASF). Processing and analysis of the data have begun.

Description of Research

Domestic reindeer husbandry is at the very core of the culture, lifestyle, and economy of the majority of the indigenous peoples in North Russia. The "Reindeer Mapper" concept was developed to create a system for information management and knowledge sharing to improve management of reindeer herds and to increase the adaptive capacity and resilience of reindeer herders to the multiple changes occurring across the Arctic. This system is designed to bring indigenous traditional and local knowledge together with scientific and engineering knowledge, remote sensing, and information technologies to address environment, weather, climate, pollution, and land use change issues to improve decision making for sustainable reindeer husbandry, and to improve the quality of life of reindeer herders. Geographic information systems (GIS), remote sensing technologies, and traditional knowledge from indigenous people are the main components of the project. This proposal has been accepted into the Land Cover-Land Use Change (LCLUC) Program.

Accomplishments during the Reporting Period

Over centuries, reindeer husbandry management was based on "traditional knowledge." Under conditions of stable climate and socioeconomics, this traditional knowledge was based on both long-term and practical, day-to-day knowledge. This experience provided generally positive results and relatively good conditions for reindeer husbandry during up to and through the Soviet period.

Because of recent rapid climate change, intense industrial impacts on the Arctic environment, and socioeconomic changes in Russia, traditional knowledge alone may not now be enough to sustain reindeer husbandry. Traditional knowledge, combined with long-term remote sensing observations of land and natural resources at high latitudes are important informational tools that can be used to support reindeer husbandry. These tools can improve the understanding of (and the ability to adapt to) changes in climate, the results of human activities and their consequences on ecosystems, economic productivity, and human health, and the well being of indigenous reindeer herder communities in Northern Russia. To do this, efforts were made to obtain, analyze, and integrate remote sensing data, ground-based measurements, and information technologies with indigenous traditional and local knowledge into a GIS-based information management and knowledge-sharing system, called "Reindeer Mapper."

A first task to demonstrate the application of Reindeer Mapper was the selection of an initial pilot region. The Chukotka Autonomous Okrug has been selected as an initial pilot region. The choice was made for several reasons: The area is of high priority for our reindeer herder co-investigators; reindeer husbandry is Chukotka's key traditional economic activity; the area shares many common characteristics and problems with other Russian reindeer husbandry areas; the area is within the range of the ASF receiving station, so radar data are more affordable and available than elsewhere; the Chukotka Scientific Research Center, part of the Northeast Interdisciplinary Scientific Research Center of the Far East Division of the Russian Academy of Sciences, can play a strong role in regional scientific collaboration; the region has experienced a wide range of climate, environment, and social impacts with severe consequences for the reindeer population. In the late 1980s, the domestic reindeer herd numbered over 500,000, but following the collapse of financing and supply lines to Chukotka, in addition to other factors, the herd dropped to approximately 94,000. In addition to the social impacts on the herds, huge tundra fires, which drastically decreased tundra forage, and a series of winters with unusual flash thaws, trapping the tundra forage under ice layers, caused widespread starvation in the herds.

One of the main initial contributions of satellite data to this project will be from SAR data. Because of extensive, visibility-obscuring cloud cover at high latitudes, SAR's all-weather capability allows it to provide excellent data coverage. SAR images from ERS-2 satellite are

already being analyzed using the Environment for Visualizing Images (ENVI) processing system, designed to provide comprehensive analysis of satellite remote sensing data. In particular, the image of a huge fire scar, caused by forest-tundra fires during July-August 2003 near the Vaegi settlement (Chukotka, Anadyr region), is now under analysis.

Objectives for the Coming Year

Activities for the coming year will focus on testing the SAR data application for estimating the ecological condition of reindeer pastures. Collaboration with Russian partners to prepare validation experiments will be pursued.

Task 913-13-120: **Characterization of Aerosol and Atmospheric Parameters from Spaceborne and Surface-Based Remote Sensing**

GEST Investigator: Santiago Gassó

Collaborators: Si-Chee Tsay (PI, GSFC), Jeffrey Reid (NRL), Douglas Westphal (NRL)

Abstract

In an effort to study the interaction between aerosol and clouds in the South East Asia region, development of a radiative transfer scheme that computes aerosol radiative forcing for distributions of aerosol concentration predicted by Navy Aerosol Analysis Prediction System (NAAPS) began. Analysis and comparison of aerosol mass concentration retrievals from Moderate Resolution Imaging Spectroradiometer (MODIS), sunphotometer, and *in situ* platforms with data from the Puerto Rico Dust Experiment (PRIDE) began. Continued improvements were made of the Forecast of Atmospheric Radiative and Optical Properties model (FAROP). The improvements include a flexible user interface and inclusion of default viewing geometries. The first online version was released in January 2004.

Description of Research

There are three primary motivations for the research activities carried out under this task. One is the need to understand how aerosols interact with clouds and affect radiative forcing of climate. Second, although frequent comparison studies between satellite- and model-derived aerosol optical depth have been performed in recent years, very few studies have been compared with remotely sensed, *in situ* measured and modeled aerosol mass concentrations. The third motivation is the U.S. Navy's need for aid in operational decision making to accommodate changes in visibility conditions. FAROP was designed to provide rapid visibility estimates in any part of the world for user-defined applications of space and airborne sensors.

Accomplishments during the Reporting Period

The effects of aerosol properties on radiative transfer were investigated by implementing an atmospheric radiative transfer post processor for the Naval Research Laboratory (NRL)'s Aerosol Analysis and Prediction System (NAAPS). The objective of this project consisted of improvements to the model (FAROP) that simulates the radiance measured by an airborne detector. The standard outputs of Navy Operational Global Atmospheric Prediction System (NOGAPS) and NAAPS at each grid point provide profiles of ambient temperature and moisture and aerosol mass for three aerosol species (*i.e.,* dust, smoke, and sulfates) used in the radiative transfer computations.

Because FAROP parameterizes the aerosol optical properties and utilizes a commonly used approximation of the radiative transfer equation, FAROP is fast enough to provide output in near-real time. Consequently, FAROP can be run over the global NAAPS and NOGAPS domains in less than one minute, computing 34,800 points with five viewing geometries. The code simulates two signals measured by the sensor: the radiance scattered and emitted by the target, and the diffuse radiance from the environment in the target sensor view path (*i.e.,* background noise). The ratio of these two radiances (the contrast transmittance) conveys to the user how much of the signal

reaching the sensor originated with the target. The user defines the position of the target with respect to the airborne sensor. Comparisons with more sophisticated radiative transfer codes yielded reasonable results.

A radiative transfer module based on the Fu-Liou four-stream radiation code has been implemented and adapted to use with NAAPS outputs; it computes instantaneous aerosol radiative forcings. The algorithm is currently being tested, and first simulations and comparisons with case studies are being initiated.

Aerosol mass concentrations derived from *in situ* measurement of particle size distributions during the PRIDE (summer 2000) were compared with aerosol mass concentrations derived from the MODIS and a sunphotometer on the NASA Ames AATS-14 aircraft. Comparisons between the three data sets indicating that retrievals of aerosol mass are possible from space. However, calibration problems in the *in situ* measurements cast some doubt in the absolute magnitude of the *in situ* mass concentrations. Further work is needed in order to correct these measurements.

Objectives for the Coming Year

The primary objectives for the coming year will be to model the instantaneous aerosol direct forcing from outputs of an aerosol dispersion model in clear skies and cloudy conditions, and to compare them with satellite-derived estimates of forcing. A reanalysis of aerosol data from past intensive field campaigns and comparisons of estimates of aerosol mass concentrations as measured (or derived) by different methods (*e.g.,* remote and *in situ* sensing and modeling) will be done.

Task 921-01-018: **Physical Volcanology, Planetary Geology, and Geophysics**

GEST Investigator: Susan Sakimoto

Collaborators: Herbert Frey (PI, GSFC), James Garvin (HQ), Eric Grosfils (Pomona College), Kenneth Tanaka (USGS), Tracy Gregg (SUNY, Buffalo), Lori Glaze (Proxemy Research), Scott Hughes (Idaho State University), John Chadwick (Idaho State University), Karen Kortz (Community College of Rhode Island), Jacob Bleacher (Arizona State University), Serena Weren (Franklin and Marshall College), Kelly Kolb (Villanova University), Erin Frey (South River High School, MD), Emily King, (Central High School, MD), Zachary Drillings (White Plains High School, NY)

Abstract

Research for this task covers a wide range of planetary geology, geophysics and terrestrial physical volcanology objectives that are important for understanding planetary surface processes such as volcanism, cratering, and surface water flow. Remote sensing data, field studies, laboratory data, and modeling approaches are used. Recent findings address global water and volcanism patterns on Mars, and the role of water in volcanic topographic expression on Mars and the Earth, along with other related topics. Venusian volcanism is also addressed. Significant education and outreach activities were also undertaken.

Description of Research

Research objectives for this task include two related topics. The first is to understand terrestrial volcanic lava flow and cooling. This is done by studying channelized lava flows and small volcanic edifices on Earth and the terrestrial planets. This is done by combining field, experimental, analytic, and computational studies. Since small edifices, channelized lava flows, and lava tubes are common volcanic features on the terrestrial planets, the results are widely applicable to terrestrial hazard and volcanic history studies, and to estimates of planetary resurfacing and volcanic production. The second research

objective is to use topography as a constraint to understand how impact cratering and volcanic processes have played a role in terrestrial, Venusian, and Martian history and volcanic/ thermal evolution. This research uses spacecraft data, including Mars Orbiter Laser Altimeter (MOLA) topography, Magellan topography, and images of Venus, Viking and Mars Global Surveyor (MGS) images, Mars Odyssey hydrogen abundance data, and Thermal Emission data. The space data are input into models of volcanic flow and edifice construction, eruption, and impact cratering. This work is supported by MOLA Mission funds and NASA grants to several PIs and Co-Is through related grants.

Accomplishments during the Reporting Period

Significant advances have been made in several research areas. A large fraction of this effort has been in looking at the global patterns of water and volcanism on Mars, and understanding how water plays a role in topographic expressions of volcanism on both Earth and Mars. Modeling efforts addressing Venus volcanism in grabens were done with a former student (K. Kortz). Investigations continued with another student (Erin Frey) into the relationships between gullies and Martian surface hydrogen abundance. Work continued with grant collaborators on generating, providing, and analyzing models, leading to interpretation of Martian magma chamber models, Martian lava flow and patera models, and some Martian impact cratering work.

In addition to guiding and participating in these research activities, the GEST investigator served as the Geological Society of America Planetary Geology Division's "Past Chair" from November 2002 through November 2003, served as chair on the Geological Society of America's Gilbert Award Committee, and served as a GEST Council member and group leader of the former Land Surfaces and Hydrology Group.

Education and public outreach service included working with the *Earth and Sky Radio Series* to review a dozen radio scripts; working with nearly a dozen students—from high school to graduate school level—on assorted research projects; teaching a graduate-level spring semester course at The Johns Hopkins University for inservice teachers in their Masters of Science in Education program; and collaborating on a renewal for a Goddard Director's Discretionary Fund Award to investigate making three-dimensional topography models of Earth and Mars for educational use in classrooms, museums, and for visually disabled students. One set of these models is now being used by the Smithsonian Air and Space Museum. Student work this year has gone particularly well, with several student-led publications in that are either in peer review or already published, awards for entries in the Intel National Science Fair and the Intel Science Talent Search, and several students successfully competing for full fellowships at several educational levels.

Objectives for the Coming Year

This coming year will be occupied with several topics. First, work will continue on remote and field measurements of Idaho's volcanic topography for comparison with Martian volcanic features, and collaborating to tie the topographic results to geochemical trends. This is being done to potentially confirm and augment initial results that suggest that some geochemical differences in volcanism can be inferred from local topographic diversity in a volcanic field. Second, collaboration will continue in studies of Martian impact cratering to determine effects of target properties on crater topography. Third, studies will continue on the relative ages of the Martian basement rocks, and participation in several Martian volcanism research projects will continue, to determine magma chamber properties, lava flow characteristics, and the relative roles and timing of geologically recent lava and water flow on Mars. Several year-'round, ongoing, and incoming summer students are expected to assist in the above research projects.

Task 923-03-067: **AERONET Ground Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Oleg Dubovik

Collaborator: Brent Holben (PI, GFSC)

Abstract

The major research efforts during the reporting period focused on developing and implementing new Aerosol Robotic Network (AERONET) inversion code to improve aerosol retrieval products. The new inversion code has a number of unique capabilities: The retrieval code can use measurements from different observational geometries (*e.g.,* solar almucantar, principal plane). The new inversion code can simultaneously retrieve aerosol and surface properties from combined upward-looking, ground-based measurements and downward-looking satellite- or aircraft-based measurements. Polarization capabilities were added, enabling AERONET to use polarimetric measurements in operational aerosol retrievals. In both intensity and polarized retrievals, AERONET has unique capabilities to account for particle nonsphericity by employing light scattering of polydisperse, randomly oriented spheroids instead of conventional spheres. This approach was proposed for desert dust retrievals and subsequently implemented in operational AERONET processing. Research also developed aerosol emission retrievals from global satellite observations and Global Ozone, Chemistry, Aerosol, and Radiative Transport model (GOCART) aerosol transport models. A book chapter, describing methodologies for numerical inversion in remote sensing, was written.

Description of Work

The lack of detailed knowledge of the optical properties of aerosols is recognized as one of the largest uncertainties in assessments of climate forcing. Ground-based aerosol remote sensing does not provide global coverage; however, its wide angular and spectral measurements of solar and sky radiation are best suited to reliably and continuously derive detailed aerosol optical properties over key locations. Therefore, ground-based aerosol measurements are widely used to validate satellite retrievals of aerosol properties and to derive high-accuracy information about local aerosol properties. The research in this GEST activity focuses on developing and improving retrieval algorithms that derive detailed aerosol optical and microphysical properties from measurements made by automatic sun-sky scanning radiometers that make up the AERONET. This globally distributed network is one of the major ground-based remote sensing facilities designed to validate aerosol retrievals obtained from satellite sensors.

During the past three decades, radiation measured from satellites, aircraft, and ground-based instruments have been successfully used to characterize the radiative properties of the land surface, oceans, atmospheric gases, aerosols, and clouds. One of the challenges in successfully implementing remote sensing is the development of a reliable inversion procedure; such procedures are required for deriving information about atmospheric or surface interactions with the observed radiation. The inversion is particularly crucial and demanding for interpreting highly complex measurements where many unknowns must be derived simultaneously. Therefore, the deployment of the next-generation of remote-sensing sensors with diverse observational capabilities will inevitably be coupled with significant research into inverse algorithm development.

Accomplishments during the Reporting Period

Numerous publications offer a wide diversity of inversion methodologies. Work performed under this task resulted in publication of a book chapter [Dubovik, 2004], the contents of which propose a generalized multiterm, least-squares formulation that unites a variety of practical inversion approaches, such as Phillips-Tikhonov-Twomey constrained inversion, Kalman filters, Newton-Gauss, and Levenberg-Marquardt iterations. The proposed methodology resulted from research developing inversion algorithms to retrieve

comprehensive aerosol properties from ground-based assets. It is an attempt to outline unified principles addressing important aspects of inversion optimization, such as accounting for errors in the input data, inverting multi-source data with different levels of accuracy, accounting for *a priori* and ancillary information, estimating retrieval errors, clarifying the potential for employing different mathematical inverse operations, and accelerating iterative convergence.

Objectives for the Coming Year

A primary objective for the coming year is to further develop and improve the inversion code employed by AERONET used to retrieve aerosol optical properties from measurements of atmospheric radiation. Specifically, research will incorporate polarization measurements into operational AERONET retrievals. Also, the flexibility of the new scalar inversion code that applies to measurements with various geometries of observations and a wider spectral range will be fully explored. Also planned is implementation of the inversion of AERONET measurements with simultaneous airborne Cloud Absorption Radiometer (CAR) measurements and/or Multiangle Imaging Scanning Radiometer (MISR) and/or Moderate Resolution Imaging Spectroradiometer (MODIS) observations.

Task 923-03-067: **AERONET Ground-Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Thomas F. Eck

Collaborator: Brent N. Holben (PI, GSFC)

Abstract

Field visits to Thailand in both February and November 2003 were made to develop Aerosol Robotic Network (AERONET) monitoring sites and to foster scientific collaboration. Four sites were established in Thailand and two in Vietnam in February; three of the Thailand sites will continue long-term monitoring. Analysis began on aerosol optical properties of sites in Southeast Asia affected by smoke, pollution, and long-range transport of mixed aerosols from India and China. Investigations were made into the seasonal and regional variability of aerosol optical depth (AOD) in the east-central Asia region (*i.e.,* China, Korea, and Japan), including long-range transport to the mid-Pacific (*i.e.,* the Hawaiian Islands). Large dynamics in both size distributions and spectral single scattering albedo were quantified in both fine- and coarse-mode aerosol components. Analysis of the optical properties of smoke aerosols was completed for cases of very high aerosol concentrations. These events represent the extreme of smoke particle accumulation mode growth due to increased growth rates by coagulation at high concentrations.

Description of Research

The primary motivation for the investigation of the optical properties of atmospheric aerosols is for application to studies of the effects of aerosols on climate, and to validate satellite retrievals of aerosol properties. The research in this GEST activity centers on analysis of measurements made by automatic sun-sky scanning radiometers that are globally distributed as a part of the NASA-managed AERONET. The measurements of spectral direct sun intensity and sky radiance distributions are used to infer a complete description of the optical properties of aerosols. These ground-based remote sensing retrievals of aerosol optical properties are analyzed to better understand the dynamics of aerosol properties as a function of source region, transport, aging processes, and interactions with clouds.

Accomplishments during the Reporting Period

A primary scientific focus of this task was the establishment of AERONET monitoring sites and scientific collaboration in Southeast Asia (Thailand and Vietnam). This entailed visits to Thailand to establish four new AERONET

monitoring sites. One site was installed at Chulalongkorn University in Bangkok, one on a mountain ridge in the northeast (Om Koi, a Doppler radar site), one on the coast southwest of Bangkok (at Hua Hin, Doppler radar nearby), and one on the northeast plateau (Phimai, also a Doppler radar site). Sites managers were instructed on maintenance and troubleshooting of instrumentation; educational seminars were also given in Bangkok. The biomass-burning season in Thailand peaks from February through April, and data from these sites is providing some of the first accurate characterizations of aerosol optical properties in Southeast Asia. Development of the AERONET monitoring sites in Thailand continued during travel in November 2003 via collaboration with Dr. Jariya Boonjawat, Chulalongkorn University, Bangkok. A new site was established on 7 November 2003 at Mukdahan, Thailand. Under this task, we participated in a workshop regarding the SKYNET network—a network of Asian sites that are instrumented with sun/sky scanning Prede instruments, solar radiative flux sensors, lidars, wind profilers, and other remote sensing and *in situ* sensors to characterize aerosols and their effects on radiative forcing. Analysis of AERONET data from east-central Asia sites in northern China (Beijing, Dunhuang and Yulin), South Korea (Anmyon), and other sites in Mongolia and Japan continued. The almucantar retrievals processed with the new Dubovik spheroid model algorithm were used, since nonspherical desert dust particles are frequently present in this region in spring. Large dynamics in both size distributions and spectral single scattering albedo were quantified for both fine- and coarse-mode aerosol components for many of these sites. Transport of aerosols from Asia to mid-Pacific Hawaiian Islands in spring (March-May) was also investigated with multiyear data sets from AERONET sites in Lanai, Mauna Loa, and Midway. The optical properties of smoke aerosols for cases of extremely high aerosol concentrations represent the extreme of smoke particle accumulation mode growth due to increased growth rates by coagulation at high concentrations. Comparisons of long-range smoke transport cases (at GSFC from Quebec taiga fires on 8 July 2002; at Moldova on 11 September 2002 from boreal peat fires in Russia) to source region cases (savanna burning in Zambia; tropical forest and pasture burning in Brazil) show a very wide range in absorption, ranging from nearly nonabsorbing (peat fires) to strongly absorbing (savanna fires). Fine-mode smoke particles from these regions showed a wide range of sizes, due to a combination of factors including aerosol age (distance from source), combustion type, (flaming/smoldering ratio), and smoke composition (fuel type).

Objectives for the Coming Year

Work on the aerosol optical properties in east-central Asia (N. China, Korea, Japan) will include analysis of retrievals of aerosol size distributions, refractive indices, and single scattering albedo from sites that typically have mixtures of fine and coarse mode aerosols. These sites often have nonspherical desert dust aerosol present, therefore the analyses will continue to use the new spheroid particle-shape retrieval algorithm developed by Dubovik. Another objective will be to continue analysis of data from AERONET monitoring sites in Southeast Asia (Thailand and Vietnam) to study the dynamics of biomass burning, urban aerosol optical properties, and the transport of aerosols in this region.

Task 923-03-067: **Analysis of Aerosol Optical Data: Aerosol Robotic Network Ground-Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Norm T. O'Neill

Collaborators: Brent Holben (PI, GFSC), Tom Eck (GEST), Sasha Smirnov (GEST), Oleg Dubovik (GEST), Alain Royer (Université de Sherbrooke, Canada), Kevin Strawbridge (MSC, Canada), Jack McConnell (York University, Canada), Richard Menard (CMC, Canada)

Abstract

Significant advances have been made in developing and validating an algorithm for the spectral separation of coarse and fine-mode contributions to aerosol optical depth. Research activity in evaluating the third-generation general circulation model (GCMIII)/climatological aerosol model (CAM) climatological aerosol model and the global environmental multiscale (GEM)-air quality (AQ) model using Aerosol Robotic Network (AERONET) and the Aerosols in Canada Network (AEROCAN) data has focused on developing relevant quality indicators of data/model comparisons which account for instrumental and model limitations. A third research activity centered on analysis of spectral curvature in boreal smoke data. Significant curvature trends, indicative of particle-size increase and reduced absorption as a function of particle trajectory time, were found in multistation sunphotometer data acquired during the Québec smoke event of 2002 and the western Canadian fires of 1998. A fourth research activity involved the analysis of synchronously acquired scanning lidar and sunphotometer data. An analysis of a pollution event at the mouth of the Fraser Valley (British Columbia) demonstrated that the two sets of data, along with *in situ* aerosol measurements and radiosonde meteorological data, yielded a more comprehensive understanding of local aerosol optical properties.

Description of Research

The research addressed under this task was done during a sabbatical visit to GEST. It complements and augments similar work being done at the investigator's home university. Four areas are addressed: The first deals with fine and coarse-mode discrimination using the first and second-order spectral information from AERONET spectra to discriminate fine (submicron) and coarse (supermicron) contributions to total optical depth. The second area deals with model validation by comparing, at a climatological scale, AERONET/AEROCAN data with outputs from the GCMIII/CAM model, and at a meteorological scale, AERONET/AEROCAN data with GEM-AQ results. The third area addresses fine-mode spectral curvature analysis using data from the Québec smoke event of 2002 and the western Canadian smoke event of 1998 in terms of robust spectral parameters common to these two events. Finally, analysis of the Fraser Valley experiment is performed using AERONET/AEROCAN, ground-based scanning and airborne lidar data, synchronously during August of 2001.

Accomplishments during the Reporting Period

A variety of different test cases were investigated to explore the global applicability of the spectral algorithm. These included comparisons over AERONET sites affected by different types of regional aerosols and clouds, comparisons with the Moderate Resolution Imaging Spectroradiometer (MODIS) fine and coarse-mode aerosol optical depth products, and comparisons with lidar profiles. The algorithm has demonstrated its utility in terms of discriminating thin homogeneous cloud optical depth from total aerosol optical depth data and in estimating fine-mode aerosol optical depth during pollution and biomass burning events [O'Neill *et al.* 2003b]. The appearance of anomalies in specific cases indicated that the algorithm and its associated stochastic error model need to be made more cognizant of and resistant to instrumental artifacts.

AERONET measurements of aerosol optical depth and the Ångstrom exponent were compared with the GCMIII/CAM model for sites chosen to be

representative of different types of aerosols. This work is still in its developmental stages, and considerable effort has gone into defining relevant quality indicators that would account for instrumental and model limitations. At the meteorological scale, (but with the same aerosol physics package as GCMIII) runs of GEM-AQ were compared with AERONET, MODIS, and Total Ozone Mapping Spectrometer (TOMS) data at the end of the reporting period.

Significant spectral curvature trends, indicative of particle size increase as well as reduced absorption as a function of particle trajectory time, were found in multistation sunphotometer data acquired during the Québec smoke event of 2002. The interrelationships between the derived spectral parameters (*i.e.,* the first and second spectral derivatives) were generalized in terms of applicable Mie theory.

Analysis of synchronously acquired scanning lidar and sunphotometer data demonstrated, in general, that the two sets of data, along with *in situ* aerosol measurements and radiosonde meteorological data yielded a more comprehensive understanding of local aerosol optics [O'Neill *et al*. 2003a]. One key finding was that the extinction-to-backscatter ratios derived from the sunphotometry and sky radiometry inversions could be rendered more compatible with values derived from the combination of sunphotometry and lidar backscatter analysis by simply adding more coarse-mode particles of high refractive index to the AERONET inversions; this had practically no effect on inversion residuals.

Objectives for the Coming Year

The objectives for the coming year include a series of lidar/sunphotometry experiments at the Egbert MSC (Meteorological Services of Canada) site and a cross-border pollution study, using the scanning lidar and sunphotometer on a mobile trailer to acquire synchronous data. The comparisons with the GCMIII/CAM model will have matured sufficiently to contemplate a peer-reviewed publication. The GEM-AQ comparisons will continue beyond the Québec smoke evaluation to other pollution events for which we are currently amassing substantial source and surveillance data.

Task 923-03-067: **Validation of Total Ozone Mapping Spectrometer Aerosol Products and Comparison with Other Satellite Products**

GEST Investigator: Alexander Siniuk

Collaborators: Jay Herman (PI, GSFC), Omar Torres (UMBC, Physics/JCET)

Abstract

The research conducted during the past year addressed two main problems. One focused on the validation of Total Ozone Mapping Spectrometer (TOMS) aerosol products. As a part of a validation procedure, the aerosol models used in the TOMS retrieval algorithm have been revised and the new models have been implemented in TOMS and Ozone Monitoring Instrument (OMI) aerosol retrieval algorithms. Comparison of TOMS retrieval results with those produced by the Aerosol Robotic Network (AERONET) retrieval algorithm has been conducted for a number of additional AERONET sites. The second part of the research includes testing the performance of the new aerosol algorithm for the OMI. Synthetic data have been generated that imitate the real aerosol behavior on a global basis.

Description of Research

The research under this task tests the correctness of the assumptions implemented in TOMS and OMI aerosol retrieval algorithms. Research activities include analysis and selection of candidate aerosol models to be used in the algorithms, and testing the algorithms' performance by using synthetic data (for OMI) and comparison of retrieval results with those from the AERONET (for TOMS).

Accomplishments during the Reporting Period

New models for the three basic aerosol types (*i.e.,* desert dust, biomass burning, and sulfate) have

been selected based on the climatology of AERONET retrievals of aerosol properties. The principal advantage of the new models is the possibility of correctly reproducing the observed spectral dependence of aerosol optical depth in the wavelength range 380 to 500 nm. Thus, TOMS retrievals of optical depth in the UV could be extrapolated into the visible wavelengths by using coefficients calculated for each aerosol model selected. The new aerosol models were employed in TOMS lookup table calculations.

Synthetic data for testing the aerosol retrieval algorithm for OMI have been generated. The computer code has been developed which uses the TOMS Aerosol Index (AI), Lambert Equivalent Reflectivity, TOMS optical depth, and satellite geometry information to generate the synthetic data, which simulate real aerosol behavior on a global basis.

The aerosol models selected for the TOMS algorithm have been used for OMI look up table calculations for the three basic aerosol types.

Additional work was devoted to developing an alternative aerosol retrieval algorithm for the OMI. The algorithm is based on statistical estimation theory, and will allow retrieval of an extended set of aerosol parameters (*i.e.,* optical depth, aerosol altitude, the imaginary part of the refractive index, and surface albedo) from a combination of data from the UV and the visible part of spectrum. The computer code has been developed, and some simple tests have been conducted.

Objectives for the Coming Year

In the coming year, research devoted to validation of TOMS aerosol products will continue. Another objective is to complete the development of the new aerosol algorithm for the OMI and to explore the possibilities provided by the combination of satellite measurements in the UV and visible part of spectrum.

The GEST investigator has joined the ranks of GSFC contractors.

Task 923-03-067: **Aerosol Robotic Network Ground-Based Remote Sensing of Aerosol Optical Properties**

GEST Investigator: Alexander Smirnov

Collaborator: Brent N. Holben (PI, GSFC)

Abstract

Research focused on the analyses of the maritime aerosol component derived using Aerosol Robotic Network (AERONET) data from island locations in the Atlantic, Pacific, and Indian Oceans. Multisite multiyear aerosol optical depth data from AERONET provided a unique opportunity for a comprehensive analysis of aerosol variations over the oceans. The aerosol optical model includes information about optical parameters (*i.e.*, aerosol optical depth and its spectral dependence, phase function, and single scattering albedo) and microphysical characteristics (*i.e.,* size distribution and its parameters and refractive index). The effect of wind speed on the concentration and size distribution of aerosols over the oceans was comprehensively studied.

Description of Research

Remotely measured atmospheric aerosol optical parameters are important for various applications including computation of radiative forcing and satellite remote sensing. Aerosol optical depth, which may be derived from measurements of attenuated direct solar radiation, and the aerosol size distribution and single-scattering albedo, which may be derived from combined aerosol optical depth and solar almucantar sky radiance data, are pivotal parameters defining the aerosol optical state of the atmosphere. The major advantage of these kinds of remote sensing measurements over direct *in situ* aerosol sampling or laboratory analysis is their large-scale (column-integrated) quantities and nonintrusive nature. The World Ocean covers approximately 70% of

Earth's surface and is one of the major sources of natural aerosols. The quality of bio-optical products of satellite ocean color sensors is strongly dependent on the accuracy of atmospheric correction algorithms. Aerosol optical properties over the oceans vary considerably, depending on contributions of major aerosol components, *i.e.*, urban/industrial pollution, desert dust, biomass burning, and oceans. The optical characterization of these aerosols is fundamental to the parameterization of radiative forcing models as well as to the atmospheric correction of ocean color imagery.

Accomplishments during the Reporting Period

A model of the maritime aerosol component was derived using AERONET data from island locations. The aerosol optical model includes information about optical parameters (*i.e.,* aerosol optical depth and its spectral dependence, phase function, and single scattering albedo) and microphysical characteristics (*i.e.,* size distribution and its parameters, refractive index). The aerosol model can be employed as a maritime lookup table (LUT) kernel in coupled atmospheric retrieval and correction algorithms. It can also be advantageously employed as a LUT inversion kernel in pure aerosol retrieval schemes or in algorithms for classifying of aerosol mixtures. The maritime aerosol model can be used as the defining single component of pure maritime air masses or in combination with various aerosol types (*e.g.,* dust, biomass burning, etc.). Finally, the model can serve as a source of input to aerosol transport models and radiative forcing simulations. The model encompasses a variety of maritime conditions in the simplest manner possible. However, it requires further validation, based on the accumulated evidence of microphysical and optical measurements tied to radiative transfer closure experiments.

Aerosol optical parameters derived from data obtained at the operational AERONET site on Midway Island were studied to develop a relationship between surface wind speed and optical properties. Midway Island is situated in the Northwestern Pacific Ocean, almost equidistant from the United States and Japan. In general, optical conditions over Midway resemble aerosol found over other maritime locations in the Pacific Ocean (*e.g.,* Lanai, Tahiti, Nauru). Wind speed determines sea state (*e.g.,* wave height, whitecaps, etc.) and various formulations for sea-salt aerosol generation functions use current wind speed or average wind speed over an earlier period. Correlation coefficients at Midway between various instantaneous measured aerosol optical parameters and current or averaged wind speeds showed that correlation coefficients have maximum close to 24 hours. Averaged within various wind speed ranges, the aerosol size distributions over Midway can be reasonably well predicted with a maritime aerosol component model that combines elements of both remotely sensed and *in situ* relationships of oceanic aerosols. In considering some other island sites of the AERONET network (*e.g.,* Lanai, Nauru, Tahiti, Ascension Island) no significant correlation was found between optical parameters and wind speed. A variety of factors can mask the correlation: these may include the narrow range of wind speeds, mountainous terrain, nonuniform meteorological conditions, island aerosol influence, etc. Even attempts at elimination of possible residual aerosol contamination due to volcanic contributions, dust, and biomass burning did not make the correlations any stronger at those sites. A new and potentially promising AERONET site was recently established near the "roaring forties" latitudes of the Southern hemisphere (specifically, Amsterdam Island). After a number of years of data collection it may offer a more comprehensive data set, especially for conditions of very high wind speeds (over 10 m/s).

Objectives for the Coming Year

Goals for the next year will focus on developing the maritime aerosol optical model, refining the AERONET processing algorithm, participating in aerosol retrieval analyses, and establishing additional AERONET sites.

Task 923-06-092: **Studies of Earth's Surface Interannual Variability Using Data from Satellites and Distributed Ground Stations**

GEST Investigator: Assaf Anyamba

Collaborators: C. Tucker (PI, GSFC), C. Justice (UMCP), B. Doorn (USDA/FAS), C. Reynolds (USDA/FAS), CDR. R. Culpepper (DoD/WRAIR-GEIS), Maj. R. Coldren (USAMRU and GEIS-Kenya), K. Linthicum (State of California, Department of Health Services)

Abstract

Part of the land surface component of the Southern African Regional Science Initiative (SAFARI) 2000 field campaign was to study linkages between land-atmosphere processes and their relationship to regional fire patterns. Differences in normalized difference vegetation index (NDVI) patterns resulted in different patterns of fire distribution for the period of study. In other work, recent floods along the Senegal River created conditions necessary for Rift valley fever (RVF) outbreaks that were reported in the region from October through December 2003. This is the second consecutive year of RVF activity in the region. The anomalous conditions in NDVI data at 8km spatial resolution have not been detected. As a result, the potential is being explored for using high-spatial-resolution data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and SPOT-Vegetation instruments to characterize areas where RVF outbreaks have occurred in the last two years. As part of the efforts to support the United Nations Environment Program (UNEP), the United Nations Food and Agriculture Organization (FAO), and the United Nations Convention to Combat Desertification (UNCCD) assessment on "Changes in the Sahel", NDVI time series data are being analyzed to investigate the interannual variability and long-term trends over the region. The variability and trends in agricultural production for this region closely mirror the departure patterns in NDVI. MODIS NDVI time series data are being analyzed and compared with Advanced Very High Resolution Radiometer (AVHRR) and SPOT NDVI data to support U.S. Department of Agriculture (USDA) Foreign Agricultural Service (FAS) global monitoring activities.

Description of Research

The primary objective of this research is to improve the understanding of the land surface response patterns to interannual forcing associated with El Niño/Southern Oscillation (ENSO) forcing using long-time series satellite vegetation measurements. This work is of critical relevance to work on ecosystems dynamics and change, applied work in environmental analyses for famine early warning, and agricultural monitoring in support of United States Agency for International Development (USAID) and USDA/FAS activities, impacts on disease outbreak patterns in support of NASA's initiative on Environment and Human Health, and the Department of Defense (DoD) Global Emerging Infections Surveillance System (GEIS). The research utilizes an array of satellite and surface observations, including vegetation index measurements from AVHRR, SPOT Vegetation, MODIS and Landsat, global sea-surface temperature (SST), outgoing longwave radiation (OLR), and precipitation data to determine the linkages between SST variability, precipitation patterns and land surface response patterns at a variety of time and space scales.

Accomplishments during the Reporting Period

Part of the land surface component of SAFARI-2000 was to study linkages between land-atmosphere processes and their relationship to regional fire patterns. Research was completed comparing vegetation anomaly patterns and fire patterns for several years. The ecosystem response to these differing rainfall patterns indicates that drought prevailed over the region, associated with the occurrence of a warm ENSO event, which resulted in a large rainfall deficit and reduced photosynthetic activity over most of the region.

These differences in NDVI patterns resulted in different patterns of fire distribution. More AVHRR satellite detections of active fires were observed for defined periods especially for Botswana, Namibia, Southern Zimbabwe, and Southern Mozambique where there was increased biomass production. Comparisons between *in situ* and airborne measurements during these periods require an understanding of the extremely different vegetation and fire conditions associated with those years. Generalizations from results of SAFARI 2000 and 1992 field campaigns must take into consideration the extreme differences in surface conditions and the large interannual variability encountered in southern Africa, as depicted by the long-term record of satellite vegetation measurements [Anyamba *et al.* 2003].

Above-normal rainfall in the Sahel region during the July-October 2003 seems to be a continuation of the rainfall trends observed over the region since 1994. Recent floods along the Senegal River created conditions necessary for RVF outbreaks, which were reported in the region from October through December 2003. This is the second consecutive year of RVF activity in the region. However, we have not been able to detect the anomalous conditions in NDVI data at 8-km spatial resolution. As a result, the potential is being explored for using high-spatial-resolution data from MODIS and SPOT-Vegetation to characterize areas where RVF outbreaks have occurred in the last two years.

As part of the efforts to support the UNEP, the FAO, and the UNCCD assessment of "Changes in the Sahel", NDVI time series data are being used to investigate the interannual variability and long-term trends over the region. Partial results indicate there are two general anomaly patterns: one, marked by below average vegetation and persistence of drought with a signature large-scale drought; and another, marked by a trend towards "greener" conditions with region-wide, above-normal vegetation conditions. These patterns generally agree with recent region-wide trends in Sahel rainfall. However, taken in the context of long-term Sahel climate history, these conditions are still far below the wetter conditions that prevailed from 1930 to 1965. The variability and trends in agricultural production for this region closely mirror the departure patterns in NDVI. The NDVI data showed that 1984 was the year of the most severe drought resulting in the lowest production in 20 years. This was the lowest point after several years of progressively decreased production from 1980 to 1985, following years of persistent drought during the 1970s. Similar patterns are observed for maize production in Kenya and Zimbabwe and beef production in Botswana [Anyamba *et al.* 2004]. Currently, MODIS NDVI time series data are being analyzed and compared with AVHRR and SPOT NDVI data as part of the research and development work to support USDA/FAS global agricultural monitoring activities.

Objectives for the Coming Year

In the coming year, work will continue in analyzing MODIS vegetation index time series in comparison with SPOT Vegetation and AVHRR NDVI time series to provide a coherent multisatellite data base for agricultural monitoring purposes and to examine patterns of agricultural production in relation to interannual climate variability, particularly in Australia and Southern Africa. The existing work on RVF monitoring will continue, with a specific focus on understanding the recent RVF activity in the Sahel region using high-resolution data from MODIS and SPOT, and on analyzing recent RVF activity in Egypt, Saudi Arabia, and Yemen. Other work will include managing Global Inventory Mapping and Monitoring Studies (GIMMS) contributions to support the application of MODIS data to agricultural assessment and forecasting by the USDA/FAS as part of the combined FAS/UMD/GSFC activities for this program. Support to USAID/ Famine Early Warning System Network (FEWSNET) and DoD/GEIS program activities will continue.

Task 923-32-162: **Development of an Advanced Atmospheric Correction Algorithm for Earth Observing System Instruments**

GEST Investigator: Alexei Lyapustin

Collaborators: J. Privette (PI, GSFC), Yujie Wang (GEST)

Abstract

Recent theoretical studies have shown that three-dimensional radiation effects caused by the surface inhomogeneity play an important role in the optical remote sensing of atmospheric aerosol and land surface reflectance [Lyapustin and Kaufman 2001]. They may contribute notably to the error budget of retrievals in a broad range of sensor resolutions, from Landsat to the Earth Observing System (EOS)'s Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR) scales. The current work is dedicated to developing the accurate atmospheric correction (AC) algorithms for MODIS and MISR, and the Landsat Enhanced Thematic Mapper + (ETM+) imager. Part of this task is to develop a fast and accurate method to derive shortwave broadband calculations that accurately captures atmospheric gaseous absorption at arbitrary spectral resolution. Capabilities developed using present missions will be adapted for the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

Description of Research

The main objective of our research is developing generic aerosol retrieval and atmospheric correction algorithms for EOS instruments MODIS and MISR, and the Landsat ETM+ imager. The new algorithm is based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties [Lyapustin and Knyazikhin 2001; 2002]. Another direction is developing constrained AC algorithm that uses ancillary aerosol and water vapor information from the Aerosol Robotic Network (AERONET).

Accomplishments during the Reporting Period

In the past year, work continued on incorporating atmospheric gaseous absorption into the radiative transfer (RT) code SHARM using the new Interpolation and Profile Correction (IPC) method [Lyapustin 2003]. The IPC method allows fast RT calculations with any arbitrary spectral resolution, including monochromatic mode, with an accuracy of the line-by-line (LBL) methods. The IPC calculations are based on the LBL absorption of main atmospheric gases from the latest HITRAN2000 spectroscopy and a related model of water vapor continuum. In collaboration with Dr. Yujie Wang (GEST), a theoretical basis has been developed for non-Lambertian retrieval of the surface bidirectional reflectance distribution function (BRDF) and albedo for MODIS and MISR instruments. In collaboration with Dr. Michael King (GSFC) and Dr. Charles Gatebe (GEST), we have developed a rigorous AC algorithm for the Cloud Absorption Radiometer (CAR) that was applied to process CAR measurements of the ocean BRDF acquired during the Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) campaign of 2001 [Gatebe *et al.* 2004]. The new algorithm evaluates simultaneously the wind speed from the glint pattern, and the water leaving radiance.

Objectives for the Coming Year

This effort, supported by the NPOESS Preparatory Project (NPP) and EOS grant funding (2004-2006), will concentrate on developing the advanced global atmospheric correction algorithms for MODIS and Landsat, and developing the AERONET-based Surface Reflectance Validation Network (A-SRVN). Analysis of the VIIRS aerosol retrieval and atmospheric correction algorithms/codes will continue. In other work, the present algorithm for

atmospheric correction does not yet realize the full potential of MODIS measurements for climate change research. For example, when retrieving the BRDF in the Lambertian approximation, biases of aerosol retrieval over nonvegetated surfaces, absence of the radiative energy conservation constraints, and other factors limit the accuracy of MODLAND processing. On the other hand, our theoretical research and code development of the last five years has built a solid foundation for improving the accuracy of land surface reflectance products over vegetated surfaces. A new generic approach to aerosol retrieval and atmospheric correction over non-vegetated and bright surfaces will be studied.

Task 923-32-162: **Algorithm Development and Validation for Land Surface and Atmospheric Products for VIIRS**

GEST Investigator: Yujie Wang

Collaborators: J. Privette (PI, GSFC), Alexei Lyapustin (GEST)

Abstract

Recent developments in 3-D radiative transfer theory of atmosphere showed that three-dimensional radiation effects caused by the surface inhomogeneity play an important role in the optical remote sensing of atmospheric aerosols and land surface reflectance. They may contribute notably to the error budget of retrievals in a broad range of sensor resolutions, from Landsat to Earth Observing System (EOS)'s Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR) scales. The current work is dedicated to implement this new 3-D theory to a new and more accurate atmospheric correction algorithm for the EOS instruments MODIS and MISR, and the Landsat Enhanced Thematic Mapper + (ETM+) imager, establishing a global validation network based on Aerosol Robotic Network (AERONET) stations. The retrieved surface reflectance is used for validation purposes and to generate a "surface climatology" to improve satellite aerosol retrievals.

Description of Research

The main objective of our research is to develop an aerosol retrieval and atmospheric correction algorithm that is independent of sensor and spatial resolution effects. For MODIS, MISR, and Landsat ETM+ imager, the algorithm will be validated using the AERONET global validation network. The retrieved surface reflectance will be used for validation purposes and to generate a "surface climatology" to improve satellite aerosol retrievals. The new algorithm will be based on a recently developed theory that rigorously describes 3-D radiation effects, gaseous absorption in the atmosphere, and surface bidirectional reflectance properties.

Accomplishments during the Reporting Period

Significant effort has been made in the development of the theory and numerical codes for 3-D atmospheric radiative transfer over non-homogeneous and anisotropic surfaces [Lyapustin and Knyazikhin 2001, 2002; Lyapustin, 2002]. The new theory allows us to develop a sensor and spatial resolution independent algorithm that applies equally to all scales of the remote sensing, different instruments, and different sun-view geometries.

In the past year, our work was mainly focused on developing a rigorous 3-D radiative transfer atmospheric correction algorithm based on EOS MISR data. The new algorithm uses two types of bidirectional reflectance distribution function (BRDF) models (*e.g.,* the linear hybrid model and the Modified Rahman-Pinty-Verstraete (MRPV) model) as the starting point, and then retrieves surface BRDF and albedo through an iterative method. This algorithm will be applied to subregions centered on AERONET sites to perform a cross-instrument validation of the land surface BRDF and albedo. The sensitivity of the algorithm has also been studied.

Objectives for the Coming Year

In the coming year, a 3-D radiative transfer atmospheric correction algorithm will be developed, based on EOS MODIS data. Together with the algorithms developed for MISR and ETM+ images and using the aerosol information provided by AERONET sites, an AERONET-based Surface Reflectance Validation Network (A-SVRN) will be established to validate the full algorithm.

Task 923-37-170: **Visible and Infrared Imaging Radiometer Scanner Validation Technique**

GEST Investigator: Mohan Nirala

Collaborators: Jeffrey Privette (PI, GSFC), Robert Murphy (GSFC)

Abstract

The Visible Infrared Imager Radiometer Suite (VIIRS) of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) is similar in purpose to the successful Moderate Resolution Imaging Spectroradiometer (MODIS) now flying on the Earth Observing System (EOS) Terra and Aqua platforms. Moderate Resolution Imaging Spectroradiometer (MODIS) data are being used as surrogates for preliminary development of VIIRS validation techniques. Particular attention was paid to biases and directional uncertainties.

Description of Research

The NPOESS merges DoD and Department of Commerce (DoC) meteorological satellite systems into a single national asset. The sensors onboard NPOESS will collect and disseminate data about Earth's oceans, atmosphere, land, climate, and the space environment. The NPOESS Preparatory Project (NPP) is a bridge between the EOS program and NPOESS, and is a joint mission supported by NASA, the Department of Defense (DoD), and the National Oceanic and Atmospheric Administration (NOAA). NPP will be launched in 2006, and will carry four sensors that will continue many of the long-term climate measurement series that have been initiated by the EOS's Terra and Aqua missions.

Moderate-resolution, multispectral radiometric imaging of sea surface temperature, clouds, aerosols, and the land and ocean biosphere will be conducted by the VIIRS, a NPP sensor similar in purpose to the successful MODIS now flying on Terra and Aqua. The VIIRS collects visible/infrared imagery and radiometric data. Data types include atmospheric, clouds, Earth radiation budget, clear-air land and water surfaces, sea surface temperature, ocean color, and low-light visible imagery. It is the primary instrument for satisfying 26 Environmental Data Records (EDRs). The VIIRS will combine the radiometric accuracy of the Advanced Very High Resolution Radiometer (AVHRR), currently flown on the NOAA polar orbiters, with the high spatial resolution of the Operational Line-scan System (OLS) flown on Defense Meteorological Satellite Program (DMSP) assets. One focus of the research under this task is to validate a subset of the operational algorithms due to be produced by the NPOESS program. These include land surface temperature (LST), ice surface temperature (IST), and vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), and Leaf Area Index (LAI). Surface type data are used to estimate surface emissivity. Emissivities of surfaces change with snow, rain, and drought and from season to season. Surface-type data need to be updated relatively often. There are numerous other factors that can affect LST including wind, clouds, elevation shadow, soil moisture content, etc., which needs to be studied and possibly implemented in LST algorithm. Highly variable or unknown emissivities in the models need to be characterized and improved in future LST algorithms for climate research activities. The comprehensive use of MODIS LST, sun, and view geometry data and analysis in both the principal and nonprincipal plane is underway to examine and validate the LST EDR. The main objective is to develop a dynamic emissivity algorithm component for the VIIRS sensor.

Accomplishments during the Reporting Period
Satellite (MODIS), aircraft, and ground data from the Southern Africa Regional Science Initiative (SAFARI 2000), the Large-Scale Biosphere Atmosphere Experiment in the Amazon (LBA), and EOS core sites are being used as surrogates for VIIRS data to validate land EDRs. The SAFARI data were developed to explore, study, and understand linkages between land-atmosphere processes and the relationship to biogenic, pyrogenic, or anthropogenic emissions and the consequences of their deposition for biogeophysical and biogeochemical systems in southern Africa. The LBA Ecological Research program (LBA-ECO) is one of several international research programs designed to improve our understanding of the effects of tropical forest convection on ecosystem function and the sustainability of land use. The LBA provides new understanding of environmental control on flows of energy, water, carbon, nutrients, and trace gases between the atmosphere, hydrosphere, and biosphere of Amazônia. The field experiments with vegetation bidirectional reflectance models, and analyses using MODIS, AVHRR, Landsat, and IKONOS data are being used to validate the NPOESS products.

Biases and the directional uncertainty in the MODIS LST product were conducted. Several scenes from MODIS observations were tested for biases and directional effects (*e.g., s*un and view geometry) on LST. Analysis of both continental and smaller geographical subsets over Africa using 1 km and 5 km MODIS LST versus sensor zenith angle plots indicate directional effects in MODIS LST data in the principal plane [Nirala *et al.* 2003]. Several case studies were performed using daily MODIS Terra and Aqua data at 1- and 5-km LST data resolution.

Objectives for the Coming Year
As this investigator has left GEST, there are no objectives for the coming year.

Task 923-39-175: **NPOESS Preparatory Project System Calibration/Product Validation Studies**

GEST Investigator: Bruce Guenther (PI)

Collaborators: H. Ouaidrai, Joseph Lyu (SSAI); S. Gasster (Aerospace Corporation); J. Qu (GMU); R. Murphy, X. Xiong, V. Salomonson, (GSFC); K. St. Germain (IPO)

Abstract
The research involves continuing development of the government team for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program in the area of sensor calibration and environmental data product validation (cal/val), development and oversight of the NPOESS and NPOESS Preparatory Project (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) sensor calibration, and continuing support for the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) calibration data product. Research involves identifying and applying EOS lessons-learned in cal/val to the NPP and NPOESS calibration/val program. The VIIRS sensor builder has embraced the NASA calibration equation and is providing measurements and testing consistent with accuracy according to the calibration equation. Refinements to MODIS calibration and validation approaches have been identified and are under study. Advances were made in the NPP Engineering Development Unit (EDU) Data Exchange Project (NEXT), organized to process NPP sensor EDU calibration and characterization data.

Description of Research
Research in the NPP involves close collaboration with the NPOESS prime contractor and the Integrated Program Office (IPO) team on the optimum application of EOS lessons-learned for sensor calibration and data product validation through discussions, internal memos, presentations, conferences, and refereed publications in the open literature. For the MODIS effort, the research involves continuing collaborative research with the GSFC MODIS leadership and with the MODIS Characterization Support Team (MCST) to remain cognizant of their key accomplishments and issues, to challenge

their approaches, and to identify potential areas of improved calibration performance through analysis, presentations, and publications in the peer-reviewed literature.

Accomplishments during the Reporting Period
The principal research accomplishment for NPP VIIRS was the acceptance within the IPO community of the NASA VIIRS Thermal Emissive Bands (TEB) calibration equation. The NASA VIIRS TEB calibration equation takes proper account of the effects of sensor optics temperatures. This was accomplished through distribution of tutorial materials from the MODIS calibration effort and application of those principals for VIIRS to the IPO and the principal systems integrator staff, Northrop Grumman Space Technologies (NGST). These approaches and the sensitivity of the radiometric calibration accuracy to sensor optics temperatures were documented.

The NEXT activity moved forward with incorporation of EDU data from the four NPP sensors now incorporated within the NPP. The day-to-day science leadership for NEXT was provided within the NPP cal/val effort. A NEXT data access and data utilization policy should be completed by the time this report is published.

Objectives for the Coming Year
The main objectives for the NPP activity are to integrate the NPP Science Team into the NPP cal/val effort, analysis of NPP sensor EDU test data within the NEXT system for initial verification of sensor radiometric calibration concepts, and providing detailed comments and analysis on sensor test and analysis concepts. For MODIS, the main objectives are to complete strategies for tracking sensor mirror side differences through the use of Earth-view science data, and to begin a study to extend this approach from the reflected solar bands (RSB) to the TEB data, and assessing RSB low-signal calibration accuracy.

Task 923-46-188: **National Polar-Orbiting Operational Environmental Satellite System Preparatory Project Algorithms and Data Systems**

GEST Investigator: Peter Merheim-Kealy

Collaborators: Bruce Guenther (PI, GEST), Robert Murphy (GSFC), Jeff Privette (GSFC), Neal Baker (IPO)

Abstract
Research under this task involves continuing development, in coordination with the government team, of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) program in the area of algorithm development and algorithm operational implementation for near-real-time weather forecasting and tactical purposes. The NPOESS Preparatory Project (NPP), which relies on NPOESS for sensors and ground processing, will provide data continuity between Earth Observing System (EOS)-era measurements and the NPOESS measurements, due for operational start in 2006. Differences between the real-time needs of operational users and those of NASA's long-term climate mission are being identified, and optimal solutions are being sought.

Description of Research
The main purpose of this research is to support the Integrated Program Office (IPO) team and its industrial partner, Northrop Grumman, to optimize the development path for the required output products. The algorithm optimization process impacts all subsystems within the program from sensor requirements, algorithm integration within the operational ground system, to on-orbit calibration and validation strategies. The research is accomplished through technology review and project coordination among government, industrial, and academic partners. The climate community may use the operational products for research.

Accomplishments during the Reporting Period
As the NPOESS and NPP systems are under development, the results of this research are used

primarily as inputs to the continuing system design and optimization of these multibillion-dollar programs. The results of research are usually delivered as oral presentations at internal program meetings.

The accomplishments of this research fall into several categories. A first category is requirements updates. Many system-level, sensor-level, and ground-segment processing requirements are being updated as a result of analyses ranging from sensor stray light performance to pixel-level quality flags associated with key NPOESS products. Another important aspect is to develop operations concepts that define scenarios of how systems function and interact with other major program components. Some success has been achieved in defining the development effort required to convert sensor characterization data into operational code components. This was achieved through benchmarking the scope of the tasks against other missions of similar complexity, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), the Advanced Infrared Sounder (AIRS), and sensors on satellites comprising several European missions.

A more recent thrust to this research was to support the NPP Science Team, which was selected in October 2003, and the purpose for which is to assess the suitability of real-time operational products as a basis for developing climate data records. To serve the needs of this science team GSFC is providing some infrastructure services, such as a large computer facility the science team members can use to test various algorithm versions. The provision of test data sets from industry, the government, or from within the NPP Science team themselves required coordination across the disparate elements of the total program.

Objectives for the Coming Year

The algorithm-related system engineering optimization activity will continue in the next year. A focus will be on influencing the on-ground sensor test programs and their interaction with the calibration and geophysical products. Support to the NPP science team will increase, helping to define the concept of operations for the NPP science data segment, which will be used as an interface between the NPOESS system and the global climate research community.

Task 923-51-194: **Integrating Fluxnet-Canada with the North American Carbon Program**

GEST Investigator: Hank Margolis (PI)

Collaborators: K. Jon Ranson (GSFC), Forrest Hall (JCET), Fred Huemmrich (JCET), G. James Collatz (GSFC), Jeff Masek (GSFC), Nazmi Saleous (RSTX), Elizabeth Middleton (GSFC), Robert Knox (GSFC), Jan Gervin (GSFC), Thomas Brakke (GSFC)

Abstract

This work was recently initiated to integrate the results from the Fluxnet-Canada field program into the research activities of the GSFC Biospheric Sciences Branch and the future North American Carbon Program. Flux tower data have been used to determine if ocean reflectance bands from the two Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on Earth Observing System (EOS) platforms can be used to establish constraints on the efficiency of light use by forest ecosystems. The general feasibility of making this kind of measurement from a satellite sensor has been demonstrated; the view angle has been shown to have an important influence on the signal. Data sets are being compiled to model carbon fluxes for Canada using the Carnegie-Ames-Stanford Approach (CASA) biogeochemical cycle model. Comparing Canadian flux tower data with the MODIS gross primary productivity (GPP) algorithm has suggested that the MODIS maximum light-use efficiency is set too high. Collaboration with other researchers will help to develop four carbon cycle research proposals combining Canadian field data with remote sensing.

Description of Research

A major priority of the governments of both the United States and Canada is to combine remote sensing technologies with field studies to better understand and reduce uncertainties in dynamics of the carbon cycle in terrestrial ecosystems. Planning for increased coordination between Canadian and U.S. carbon cycle researchers has begun within the framework of the North American Carbon Program (NACP). A major Canadian contribution to the NACP will be the Fluxnet-Canada Research Network (FCRN) field program and data information system. The GEST investigator leads the FCRN. It involves 19 eddy covariance flux research sites along an east-west transect of Canadian forests and peatlands. These data provide a valuable opportunity to understand the influences of climate variability and natural disturbances on the carbon cycle in terrestrial ecosystems. Remote sensing plays a key role in scaling these local observations to regional, continental, and global scales.

Field studies by other researchers have indicated the potential of using reflectance at 531 nm to indicate photosynthetic stress via changes in the conformation of xanthophylls. The GEST investigator is working with collaborators at GSFC, UMBC, and in Canada to determine if the ocean reflectance bands of the MODIS sensor can be used to obtain viable measurements of a photosynthetic stress index (PRI) for terrestrial ecosystems.

GSFC scientists and collaborators have been working with the CASA carbon cycle model to estimate the influence of fires on the interannual variability of atmospheric CO_2, CH_4, and CO. At the global scale, the approach has involved correlating the number of hotspots to burned area extent for different regions, using MODIS-measured subregions for calibration. A Canadian hotspot and burned area data set compiled from 1995 to 2000 offer an interesting possibility to use the FCRN flux data and the CASA model to analyze temporal and spatial variability of CO_2 and CH_4 fluxes and their isotopic composition as generated from fires in Canada versus values due to ecosystem respiration. The temporal and spatial variability of carbon fluxes from fires will be estimated and eventually applied to the circumpolar boreal biome. Inverse modeling with the Goddard Earth Observing System (GEOS)-CHEM model will be combined with the forward modeling to supply additional constraints to the estimates.

The GEST investigator is also working with the GSFC EO-1 deputy mission manager to obtain Hyperion data for FCRN flux research sites. Collaboration with the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) project that is producing disturbance maps of North America. LEDAPS has agreed to provide Landsat chronosequences of FCRN sites that should prove valuable for scaling multiannual measurements of carbon flux to decadal time scales.

Accomplishments during the Reporting Period

The GEST investigator began work as a UMBC Intermittent Senior Research Scientist in January 2004. In collaboration with a graduate student, Guillaume Drolet, flux data for three sites in Saskatchewan for a three-year period of MODIS activity have been obtained from Canadian collaborators. Clear summer days, when high-quality, single-orbit MODIS images were available, have been identified; satellite data have been obtained; and the areas of interest have been identified. Initial analyses indicated that the ocean bands do not saturate over these terrestrial ecosystems, and that PRI values are within the same range as helicopter-based data. A strong view zenith angle effect has been identified, and atmospheric corrections are in progress. Work has begun with the radiative transfer model, Flight, to analyze bidirectional reflectance distribution function (BRDF) effects. Daily Canadian fire hotspot and annual burned area data have been obtained for 1995 to 2000. Considerable effort has been spent organizing and reprojecting the various input data sets that will be used in the modeling effort. Other work compared shoot-, ecosystem-, and landscape-level photosynthetic capacity during autumn acclimation in an eastern Canadian boreal cutover. An important finding is that the maximum light-use efficiency parameter in the MODIS GPP algorithm was set to high relative to that indicated by flux tower data.

Objectives for the Coming Year

Work in the coming year will continue the projects begun over the first two months of this activity, and the beginning of at least some additional projects that will be proposed in response to the NASA Research Announcement in Carbon Cycle Science. Following the development of an atmospheric correction and BRDF correction scheme, the extent to which PRI can be applied will be determined to analyze light-use efficiency in west coast Douglas fir ecosystems and eastern Canadian black spruce ecosystems. If appropriate, the index will be scaled to the panboreal biome. The data sets necessary to implement the CASA model will be further developed, and initial model runs should occur by summer. Integration of MODIS fire data and the inverse modeling is planned for the coming year. Calibration of the model with the Canadian flux sites is also expected. Separation of methane emissions from peatlands and fires is also planned.

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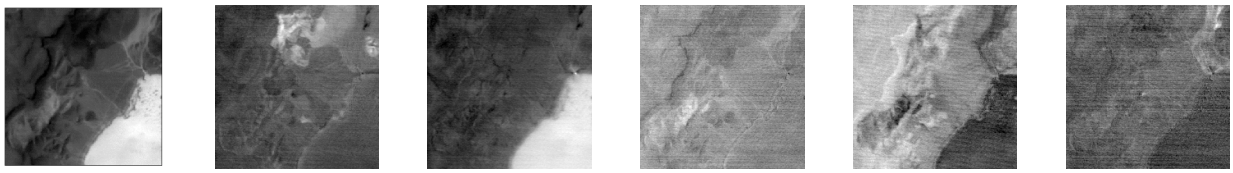
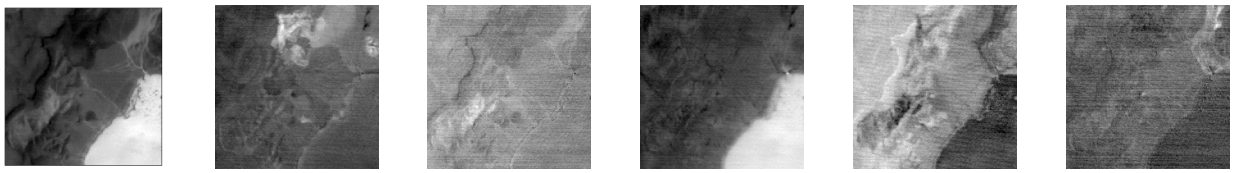
Information Science and Educational Technology Research Group



Original image | Cinders | Playa | Hyalite | Shade | Vegetation

(a) Using the image reconstructed from OSP-generated abundance fractional maps



Original image | Cinders | Playa | Hyalite | Shade | Vegetation

(b) Using the original uncompressed image

The LSMA-compression results for an AVIRIS Lunar Crater Volcanic Field (LCVF) image scene and five image endmember signatures: cinders, playa, rhyolite, shade and vegetation were identified and provided a priori for future information retrieval in classification. The LSMA used to compress data was the Orthogonal Subspace Projection (OSP). Sequences (a) and (b) are classification results based on the image data decompressed from the OSP-generated abundance fractional maps and the original uncompressed data, respectively. The classification based on LSMA-compressed data seem better than those produced by the original uncompressed data.

Figures provided by Greg Solyar

Information Science and Educational Technology Research Group

With the advent of digital detectors and the subsequent application of large-format and hyperspectral imaging in Earth and space science, the skyrocketing need for computing power and intelligent data analysis and archiving has become of paramount interest to NASA. At GEST, the end-to-end data collection, assimilation, and analysis process is studied from the computer and information science perspective. The application of emerging technologies for the benefit of education is also an important component of the Information Science and Educational Technology (IS&ET) Research Group.

While significant effort has gone into automating routine spacecraft operations, applying intelligent automation to increase science return (*i.e.,* science data acquisition and analysis) is a relatively new area of emphasis. IS&ET group members are studying ways to automatically support the science goals for spacecraft and sensors to improve understanding the capabilities needed onboard for success, thereby potentially increasing science returns and reducing perceived risks associated with increased use of automation.

One topic of increasing importance for science returns is coregistration of multiple images, which can be a complicated process. Several IS&ET activities target the challenging problem of registration of Earth and space imagery. Changes in field-of-view among images—either due to the motion of the satellite or due to the fact that the images originate from different sensors and/or different platforms—introduce uncertainties in absolute position calibration of data sets. These uncertainties are difficult to correct, given variations in viewing geometry and pixel resolution. IS&ET scientists are developing and studying algorithms to compensate for these effects, using such techniques as wavelet decomposition of the images and a new edge-detection approach.

Many image processing and analysis routines are computationally intensive and lend themselves to parallel processing. GEST scientists are developing and improving software for high-performance, parallel-computing architectures. One such activity focuses on developing system-level software and applications for implementation on Beowulf-class parallel computers—clusters of commodity PCs running Linux, connected through dedicated LANs. These clusters implement NASA's Earth and space science applications on low-cost, high-performance computers, integrated seamlessly into a working environment that consists of many personal workstations. An additional research activity in the parallel computing area is designed to give users an easy route to convert an existing structured mesh application into a form that can be run on parallel architectures. Members of the IS&ET group also work on developing and implementing new approaches to parallel programming—approaches that are needed for machines with tens or hundreds of thousands of processors—which will likely be available by the end of this decade.

Another approach being used by IS&ET researchers to attack the challenge of extracting knowledge from massive and complex data sets is to develop sophisticated data assimilation processes. The goal of this research is to integrate all that is known about atmospheric chemistry, both observationally and theoretically, to yield a "best" analysis of the atmosphere's chemical composition. This product can then be used for detailed scientific analyses of such issues as ozone depletion and its causes and changes with time and location. Data assimilation facilitates this integration and is a valuable tool in maximizing the science return from observations of atmospheric chemistry.

Ultimately, the information and knowledge from NASA's Earth and space science missions is to be communicated to scientists, educators, formal and informal students, and the general public. IS&ET activities include studies of state-of-the-art information technologies to enhance kindergarten-to-high school science, technology, engineering, and mathematics (STEM) education through Internet-based products derived from content from NASA's missions. Topics used in such learning technologies include

remote sensing of the Earth for agriculture and weather/climate studies, virtual exploration of remote worlds using robotics and digital imagery, space science and astronomy, and aeronautics. Further, IS&ET researchers, in collaboration with U.S. and Irish partners, are building the infrastructure for a virtual observatory to allow students in classrooms (and learners of all ages) to operate telescopes remotely to study astronomy and to enhance science literacy generally.

Susan Hoban

Task 130-05-085: **Learning Technologies**

GEST Investigators: Susan Hoban, Daniel Laughlin, and Marci Delaney

Collaborators: Robert Gabrys (PI, GSFC), Shane Keating (GST)

Abstract

A national need exists to address the issue of flagging performance of our nation's students in science and mathematics. Decreasing numbers of students in the U.S. are embarking upon careers in science, technology, engineering, and mathematics (STEM) — a trend that contributes to our national shortage of well-trained scientists, engineers, and computer scientists. This problem is of paramount interest to NASA. GEST researchers participate in the Leading Educators to Applications, Research, and NASA-related Educational Resources in Science (LEARNERS) initiative and the NASA Explorer Schools program to investigate the effectiveness of information technologies in addressing these issues of national importance.

Description of Research

NASA's Education Enterprise Office of Technology and Products sponsors the LEARNERS initiative, which seeks to support science, mathematics, and technology education through the infusion of NASA science content into classroom activities through the development of information technology-based educational products. LEARNERS provides educators with information technology tools for unique teaching experiences to educate and inspire the next generation of explorers, as only NASA can. The products under development provide inquiry-based, immersive experiences for learners using a variety of new educational technologies and a combination of traditional and information technology-based techniques. Further detail on specific LEARNERS activities can be found on the Web at http://learners.gsfc.nasa.gov.

NASA's Education Enterprise Explorer Schools (NES) Program seeks to advance the agency's goal to inspire the next generation of explorers and to motivate students to pursue STEM careers. The NES program supports the NASA Education Enterprise strategy by integrating new components with assets existing within the agency into a structure that facilitates local education efforts. Three-year partnerships with select schools serving grades 4 – 9 are nurtured by the NES program, affording unprecedented learning opportunities to educators, students, and families. By coordinating interaction with NASA scientists, engineers, and educators, the NES program is increasing student participation in NASA educational and enrichment activities.

The STEM Education Research and Technology (SERT) team, comprised of the GEST investigators and their collaborators, conducts research and development activities generally related to educational technologies at GSFC, other NASA centers, and in the education community. Activities focus on the infusion of NASA content into the K-12 educational and lifelong learning environments through the use of advanced information technologies. SERT researchers work with the LEARNERS investigators from universities and private industry, K-12 educators, NASA scientists and managers, and NES administrators, teachers, and students to facilitate access to NASA data, information, and technology for research on (and development of) technologies for science, mathematics, and technology education.

Accomplishments during the Reporting Period

The LEARNERS II Cooperative Agreement Notice was released in December with a proposal due date of 15 March 2004. The selection of a second round of LEARNERS projects will open new avenues of collaboration. GEST investigators Hoban and Laughlin collaborate with Dr. Gabrys, the GSFC Education Officer, to keep the LEARNERS program at the cutting-edge of immersive information technologies for educational applications. For more information, see http://learners.gsfc.nasa.gov.

The SERT team sought and received NASA funding to publish a monthly electronic newsletter to be distributed to the NASA Explorer Schools' teachers, administrators, students, and their families. Hoban supervises this effort; Laughlin is

the editor of *NASA Explorer Schools News,* and Delaney develops the content and layout for this publication. Initially distributed exclusively to the NES schools, *NASA Explorers Schools News* is now available to the general public through NASA's Educator Resource Center Network and NASA's Central Operation of Resources for Educators. For more information, see http://learners.gsfc.nasa.gov/ExplorerSchoolsNews.

The SERT team sought and received funding from the NES program to produce an ongoing series of Webcasts designed to remotely support NES teachers' use of educational technologies. The show is entitled *Teacher Tech Talk Tuesdays (T4),* and is Webcast on the first and third Tuesday of each month.

Laughlin accepted an invitation to become a member of the NASA Learning Technology Products (LTP) Advisory Board. The board members participated in the LTP Project Review 2003 to select four of ten projects funded by LTP to move on to phase two funding.

Hoban was named chair of the NES Telescope Working Group. This group is producing a *User's Guide* and a *Resource Guide* to assist NES teachers who use telescopes donated by Meade Instrument Corporation.

The SERT team made presentations presented at both the spring and fall NES retreats in 2003. The retreats focused on professional development in one of NASA's flagship education programs.
The SERT team sought and received NASA funding to develop the Advanced Resources Evaluation and Networking Area (ARENA) at GSFC. This state-of-the-art facility will test and demonstrate NASA-sponsored educational technologies.

Hoban and Laughlin participated in the proposal review for NASA's Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) Programs. The SBIR Program funds research by small businesses to meet many of NASA's research and development requirements.

Hoban and Laughlin developed an instructional module entitled *Principles of Remote Exploration (PREP*). This inquiry-based program engages students in a simulated remote exploration of Mars to establish an experiential base to foster learning opportunities and enthusiasm for science and mathematics. The activity has been well received in numerous venues, and is featured on the 2004 NES poster. Among the venues where Hoban and Laughlin have been introducing teachers and/or students to PREP are the UMBC Urban Teacher Education program and NES, both of which primarily address underserved populations. Access to all related materials is available on the Web at http://learners.gsfc.nasa.gov/PREP/.
Hoban and Laughlin sought and received National Science Foundation funding to host an international educational technology workshop in conjunction with the National University of Ireland - Maynooth. Educating with Virtual Experience (EVE) 2003 brought together teachers and technology developers from the U.S. and Europe to share experiences and outline expectations for the future course of high-end educational technology. The conference also received support from the Irish National Center for Technology and Education.

Objectives for the Coming Year

The STEM Education Research and Technology (SERT) team will continue to conduct research for strategic planning for new directions for NASA's Learning Technologies efforts, and coordinate review and selection for the LEARNERS II Cooperative Agreement Notice. The team will build on the foundations of the EVE 2003 conference. The ARENA will have testing protocols established and begin full-scale operations. The team will continue to produce *NES News* and plans to expand the format of *Teacher Tech Talk Tuesday* to allow participation in the NASA Digital Learning Network. The team will work with NES to devise a technology challenge for students aligned with NASA's Return to the Moon theme.

Task 550-06-087: **Steps Toward an Ultraviolet/Optical Fizeau Interferometer**

GEST Investigator: Gregory Solyar

Collaborators: K. Carpenter (PI, GSFC), R. Lyon (GSFC), W. Danchi (GSFC), S. Neff (GSFC), J. Berbert (GSFC), T. Mundy (UMCP)

Abstract

The Fizeau Interferometer Testbed (FIT) is a collaborative effort between GSFC, the Naval Research Laboratory (NRL), and UMBC. The testbed is designed to explore the principles of (and requirements for) the pathfinder and final Stellar Imager (SI) concepts. The goal is to demonstrate closed-loop control of a sparse array of numerous articulated mirrors to keep optical beams in phase and to optimize interferometric synthetic imaging. Building the system of seven mirror segments has been completed, and the phase retrieval algorithm to determine the system's optical aberrations has been tested.

Description of Research

The SI mission calls for 10-30, one-meter class spherical mirrors to be used in Fizeau, or image plane combination mode. The maximum baseline length for the array elements imaging is about 500 meters. The FIT will utilize 7-30 separate apertures, each with five degrees of freedom in a sparse distribution. The overall goal of this work is to demonstrate the closed-loop control of the articulated mirrors and the system overall to keep beams in phase and to optimize imaging. The work will help to determine system requirements for accuracy and stability with the further goal of translating these requirements for station keeping and formation-wide metrology into specifications for SI. The testbed will enable critical assessment of various image reconstruction algorithms and will help to investigate the optimal sampling metrology, sensitivity of the Fourier UV plane, and to determine the plane's optimal configuration.

The first prototype of FIT operates at optical wavelengths, and uses a minimum-redundancy array for the primary mirror. Extended scenes and pinholes are positioned in the focal plane of the collimator mirror assembly and illuminated by an incandescent light source via set of interference filters. The collimator mirror assembly consists of an off-axis paraboloid primary mirror and a hyperboloid secondary mirror. Elements of the spherical primary mirror array intercept the collimated light, which is then relayed to the oblate ellipsoid secondary mirror, which ultimately focuses the light onto the image focal plane. Light is split into two paths, one for phase-diversity wavefront sensing analyses and the second to be focused on two charge-coupled device (CCD) cameras. The acquired data is then relayed to a back-end parallel computer for analysis. The signals to drive the piezoelectric actuators to phase the seven mirrors are generated by a set of National Instruments data acquisition elements.

Accomplishments during the Reporting Period

The first prototype of the FIT was built and tested. A dispersed fringe sensor was designed as a tool to allow coarse alignment of the sparse elements of the system. The tests included system stability, resolution, robustness, and precision. Responsivity and sensitivity matrices were built and system elements that could support dynamic range needed for automatic control were determined.

Unstable behaviors were corrected, and most of the elements causing system multifunction were repaired and realigned. All seven sparse elements were phased within the coherence length of white light to detect interference patterns in open-loop control. The point-spread function (PSF) from an unresolved source was detected and analyzed by means of phase-diverse algorithm. Analysis of the results from the first application of this algorithm is underway, and candidate algorithms for closed-loop control are being explored.

Objectives for the Coming Year

In the coming year, the design, fabrication, and operation of the phase-diverse Fizeau imaging system will continue. A set of algorithms for

closed-loop control will be developed and performance tested, leading to a choice of the optimal candidate. The number of degrees of freedom for controlling the sparse element position will be increased from three to five. The control algorithms will be modified and tested, based on these increased degrees of freedom. Recommendations for the design of an operational space-based instrument will be provided, based on the results of these studies.

Task 588-45-185: **Science Goal Monitor: Tools for Science Goal Capturing and Onboard Goal Monitoring**

GEST Investigator: Anuradha Koratkar

Collaborators: Jeremy Jones (PI, GSFC), John Jung (GSFC), Sandy Grosvenor (GSFC)

Abstract

The Science Goal Monitor (SGM) is a prototype software tool being developed to test new strategies for implementing science-driven automation in missions. SGM enables scientists to specify what to look for and how to react in descriptive rather than technical terms. It provides a framework for specifying goals and reactions, and then monitors streams of science data to identify occurrences of the key events previously specified by the scientist. When an event occurs, the system autonomously coordinates the execution of the scientist's desired reactions. SGM is currently focused on analyzing data received from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments flying on the Earth Observing System (EOS) Terra and Aqua satellites with a dynamic, autonomous request for higher-resolution images from the EO-1 satellite based on a set of scientific criteria involving forest fires, floods, volcanoes, or other phenomena. SGM also focusses on Yale University's Small and Moderate Aperture Research Telescope System (SMARTS) observing program, modeling and testing ways in which SGM can be used to improve scientific returns on observing programs involving intrinsically variable astronomical targets.

Description of Research

The GEST investigator is the science lead for the SGM project. SGM is being developed for infusion into NASA's future missions in order to handle exponentially increasing volumes of scientific data; improve the ability to react to dynamic, opportunistic scientific goals; and help reduce mission operations costs so that multispacecraft missions—such as constellations, sensor webs etc.—will be financially feasible. While much effort has gone into automating routine spacecraft operations, applying intelligent automation to the science side (*i.e.,* science data acquisition and analysis) has been relatively underemphasized. Through SGM, there will be improvements in understanding the capabilities needed onboard for success, metrics will be developed to understand the potential increase in science returns, and an "operational" prototype will be developed so that perceived risks associated with increased use of automation can be reduced.

Accomplishments during the Reporting Period

Using a set of astronomically oriented scenarios, plans call for developing a working prototype science goal monitor to perform in-flight science-oriented processing, and dynamically and autonomously adjust science tasks accordingly; to determine realistic requirements for in-flight hardware and software, metrics to measure the monitor's scientific effectiveness, and a costs and risks analysis for developing a production flight-ready version; and to develop and document an initial protocol and standard to describe astronomical observing goals. During the past 12 months, significant progress has been made towards these objectives. The objectives have evolved on the basis of efforts to-date and opportunities encountered. The SGM project is currently focusing its prototype functionality towards the SMARTS and EO-1 collaborations.

In the EO-1 prototype collaboration, SGM serves both as a science analyzer and a multimission

coordinator in a sensor web-related application. Demonstrations so far have been relatively simple to show the basic capability of SGM. They show the promise of coordinating data from different sources, analyzing the data for a scientifically relevant event, and autonomously updating and rapidly obtaining a follow-on, scientifically relevant image in a number of different science domains, such as forest fires, volcanoes, flooding, and lake freezing.

In the forest fire demonstration, SGM served both as a science analyzer and a multimission coordinator. SGM monitored the daily list of active priority fires from the Remote Sensing Applications Center in Utah (http://www.fs.fed.us/eng/rsac). When a fire was detected in the scientist's specified region of interest, SGM analyzed the recent history of the fire from the MODIS Rapid Fire data in that area to isolate the latest center of activity. SGM then coordinated with the EO-1 planning systems to request and monitor a high-priority, high-resolution image of the fire. SGM's Web-based user interface provided the user with a live display of the status of the image request and automatically linked to the new EO-1 image when it became available. Such SGM coordination and analysis provided new data to the U.S. Forest Service within 48 hours, whereas the typical lead-time for preplanned observations could be on the order of up to 14 days.

For the volcano scenario, the scientist specified a prioritized list of volcanoes to monitor for new eruptions. SGM then monitored each volcano site using data from the MODIS instrument. When an eruption was detected, SGM coordinated with EO-1 to automatically request a high-resolution image of the volcano area. If more than one eruption was detected, SGM selected the highest priority site for the follow-on EO-1 observation. The user received the high-resolution image via the SGM Web-based user interface.

For flooding, SGM accessed data from the Dartmouth Flood Observatory (http://www.dartmouth.edu/~floods), which monitors various rivers and wetlands around the world. The QuickScat instrument was used for flood monitoring. SGM monitored these data for flooding alerts concerning a user-specified river. For this demonstration, the Brahmaputra River in India was selected. SGM detected an alert and, as in the fire and volcanoes scenarios, sent a request for a high-resolution image acquisition to EO-1. Future flood scenarios will use ground-based *in situ* sensors to predict potential flooding before it occurs, which will drive subsequent EO-1 observations of the target area.

To explore SGM utility in lake freezing events, SGM monitored a series of buoys (maintained by the University of Wisconsin) in Sparkling Lake that measure surface water temperature to determine when the lake's first freezing occurred, and to acquire an image of the lake area as soon as possible to characterize the lake environment during the transition. SGM monitored the buoy readings for several days and triggered an EO-1 observation as soon as the temperature readings showed that the lake was freezing.

In working with the SMARTS team, the current state of the planning and processing tools currently used by the SMARTS were evaluated, and work began to upgrade those tools so that SGM could eventually interface with them for automatic analysis and determination of science goals status. A baseline suite of software tools for providing the processing capabilities that SGM and SMARTS will need was established and evaluated. Work took place in collaboration with several of the science investigators on SMARTS observing campaigns to thoroughly evaluate what their science goals were and how their observing strategies change as they evaluate the observations taken to date. Three SMARTS campaigns have been identified that provide the best scenarios to test SGM, and modeling of observing strategies and science goals has begun. A variety of metrics have been defined that can be used to establish and evaluate SGM's effectiveness. Baseline measurement of these metrics has already begun.

Objectives for the Coming Year

In the Earth Science domain new science scenarios are being identified that will have more complex reasoning. For example, by accessing real-time weather data from the Geostationary Operational Environmental Satellite (GOES), SGM can coordinate with EO-1 planning to obtain cloud-

free images to maximize the scientific value of the image obtained. Future work will test, evaluate, and tune the prototype performance against baseline data; and test prototype in a "live" observing environment.

Task 693-42-179: **Data Compression Algorithms Design for LEISA**

GEST Investigator: Gregory Solyar

Collaborator: D. Reuter (PI, GSFC)

Abstract

A key to success in data compression is determined by how much information must be stored for later retrieval for future data processing. Whether or not a compression technique is effective is measured by the degree of loss in future information *retrieval* rather than information *recovery*. The most important stage of the compression process was investigated using Linear Spectral Mixture Analysis (LSMA).

Description of Research

This task supports the Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector on EO-1 by developing intelligent and adaptive algorithms based on data compression to retrieve the maximum amount of useful information from hyperspectral data. A three-stage data compression concept is under investigation. The concept consists of a hierarchical approach, where information extraction-based band selection in the first stage, followed by information retrieval-based LSMA compression in the second stage, and priority coding-based Multistage Pulse Code Modulation (MPCM) compression in the third stage. While the compression in the first two stages is designed primarily to remove spectral redundancy, the third-stage, MPCM-based compression is included to remove spatial redundancy. Unlike most compression techniques that treat remotely sensed imagery as three-dimensional (3-D) image cubes and attempt to compress the data cubes as a whole, the proposed approach does spectral and spatial coding hierarchically. It is a very flexible conceptual approach in the sense that a compression stage may be skipped when not needed.

Accomplishments during the Reporting Period

The LSMA stage is the most important component of the proposed three-stage compression. The success of data compression is determined by how to represent the information extracted from data for future information retrieval and data processing. The idea is to find an appropriate set of image endmembers that are present in the data for information retrieval. The data then can be represented by these endmembers in a suitable form. There are two ways to acquire information about these image endmembers. One is provided by *a priori* knowledge; another is obtained directly from the data in an unsupervised manner. The former generally finds application in reconnaissance, where specific objects are interest, such as particular species, search and rescue, etc. Applications of the latter approach include surveillance, and may include environmental monitoring of toxic wastes, biological agents or chemical threats, etc. In this task, LSMA-based data compression is investigated from the perspective of information retrieval, where the image endmembers range may represent targets obtained across many applications including ecology, environmental monitoring, geology, warfare, law enforcement, etc. In LSMA design, the extensive experience of the Remote Sensing Signal and Image Processing Laboratory (RSSIPL) at UMBC was used. Using the LSMA to compress remotely sensed imagery can achieve significant compression ratios because crucial information has been preserved in the images. These images, referred to as *fractional abundance images,* represent abundance fractions of image endmembers, and are useful for future fast information retrieval. In the case under study, directly dealing with these abundance fractions may be more effective than working with the

entire data set. Two major advantages result from the proposed LSMA compression approach. In the first, the image background has been significantly suppressed; in the second, the interpixel spatial correlation in the abundance fractional images has been substantially reduced, which makes the third-stage compression more effective in compressing spatial information obtained from the abundance fractional images. Since the success of the LSMA compression hinges on finding a representative set of image endmembers for the LSMA, this task investigates various approaches that can be used to generate a desired image endmember set in supervised or unsupervised manners. A study of the proposed LSMA compression was demonstrated in experiments addressing two cases, one, where the knowledge of image endmembers is given *a priori*, and a second, where such knowledge is not available.

Objectives for the Coming Year

The data three-stage LSMA compression algorithm will be applied to LEISA's hyperspectral data. There is significant difficulty in this task because the data were not corrected, nor were they completely calibrated.

Task 902-00-006: **Executive Science/Technology Secretariat Support to NASA-HQ/ESE**

GEST Investigator: Sushel Unninayar

Collaborator: Lola Olsen (PI, GSFC)

Abstract

This task provides policy-level scientific planning and technological support to NASA HQ's Earth Science Enterprise (ESE) on interagency (U.S.) and international programs and projects dealing with all aspects/themes of the U.S. Climate Change Science Program (incorporating the U.S. Global Change Research Program (USGCRP) and the President's initiative on Climate Change Research (CCRI)); the World Climate Research Program (WCRP); the International Geosphere-Biosphere Program (IGBP); the Integrated Global Observing Strategy (IGOS); and the recently initiated International Group on Earth Observations following the Earth Summit on developing a plan for the creation of a Global Earth Observation System of Systems (GEOSS); the Global Climate Observing System (GCOS); the international WCRP Global Energy and Water Cycle Experiment (GEWEX); the new Global Observing Systems' initiative of the World Meteorological Organization (WMO/GOS); NASA/ESE's and GCRP/CCRI's cross-cutting climate modeling, observing systems, and data assimilation initiatives; follow-up on the environmental themes of the UN Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee (UN-COPUOS/STSC); interfaces with the UN Framework Convention on Climate Change (UNFCCC); interfaces with the science assessments of the Intergovernmental Panel on Climate Change (IPCC); and interactions with the boards, committees, and panels of the National Academies of Sciences (NAS), the National Research Council (NRC), and others.

Description of Research

NASA Headquarters assigned this task to GEST through the Global Change Data Center (GCDC) in GSFC's Earth Science Directorate (Code 900). It provides the necessary scientific, technological, and research leadership support required by the White House's Office of Science and Technology Policy (OSTP)'s Committee on Environment and Natural Resource's (CENR). The task also supports NASA HQ in a variety of other NASA/ESE's internal, interagency, and international programs, such as the Global Water and Energy Cycles Program (GEWEC); U.S. participation in the GCOS, as called for by the Conference of Parties (COP) to the UNFCCC; the science assessments of the IPCC, the international WCRP/GEWEX program, the international IGOS, and now the Earth Observing System (EOS)-GEOSS, the Committee on Earth Observation Satellites (COEOS), etc.

Accomplishments during the Reporting Period

Work over the reporting period involved continued and extensive interactions with the U.S. Climate

Change Science Program (CCSP—incorporating the USGCRP and the Presidential initiative on CCRI) regarding the development and initial implementation phases of the long-term strategic scientific plans as directed by the OSTP and the Office of Management and Budget (OMB). The CCSP represents, de facto, the U.S. response to the COP dealing with UN Convention on Climate Change, which has not yet been ratified by the U.S. A new strategy was proposed to accelerate development of the interagency implementation plan for the CCSP-Global Water Cycle (GWC), focusing on three integrating themes, and involving the Investigators Working Group (IWG) Science Steering Group (SSG), and the external research and applications communities. Other activities contributed to developing (with the WCRP-Satellite WG) a new strategy to implement WCRP's requirements for space-based observations. Coordination continued with WCRP/GEWEX. The GEST investigator is coauthor of the IGOS-P-Global Water Cycle Theme Report, which is in preparation. The Framework Document for the 10-year Implementation Plan for the GEOSS was reviewed and revised; this document will be submitted to the Tokyo (Ministerial) Summit on Earth Observations to be held in 2004. The GEST investigator also wrote and reviewed sections of all other inputs to the U.S. CCSP. Work continued on revisions to agency-wide plans for NASA's Energy Water Cycle Study (NEWS). Several new proposals were submitted to the CCSP for better coordination of U.S. (and international) climate modeling activities, and a "process" for how they could/should be improved. Other work included initial development of a strategic plan to improve climate models and climate predictions.

Activities during the reporting period also included continuing the implementation of the space-based observing systems component of the U.S. Detailed National Report on Systematic Observations for Climate, under the auspices of the U.S. Global Climate Observing System Program and the UNFCCC COP. Work continues in support of WMO's High-Level Panel on Future Global Observing Systems, including reviews of scientific requirements for WMO/GOS. Documentation prepared previously on requirements and scope for a future GOS was submitted to the WMO and was subsequently accepted by the WMO Executive Council. Following this, the WMO established a WMO Space Program. Various sessions were chaired at meetings and conferences. Numerous inputs to various science planning documents were written. The GEST investigator is also a member of several interagency working groups.

Research continued on forced, bounded, nonlinear, chaotic-dynamic systems, and climate system modeling and climate prediction modeling and applications. Initial concepts for a generalized continent-scale land surface-hydrology model were developed, as were initial concepts for incorporating dynamic vegetation and land surface in global and regional Earth system models utilizing the Earth Observing System (EOS) series satellite data.

Objectives for the Coming Year

Work for the coming year will continue policy-level executive science/technology secretariat support to NASA's ESE, and other activities as developed by NASA's ESE and international programs. Follow-on research will continue support to a large swath of national and international programs and projects by developing concise plans for their implementation. Research will continue on nonlinear, forced, bounded systems and climate system modeling and applications.

Task 930-01-023: **Globalization of Regional Atmospheric Models**

GEST Investigator: Miodrag Rančić (PI)

Collaborators: Jim Fischer (GSFC), Hai Zhang (UMBC)

Abstract
The objective of this project is to develop a prototype of the numerical framework to globalize regional atmospheric models. This globalization framework (GF) is based on application of quasi-uniform (QU) spherical grids and different strategies to include variable resolution (VR). GF is expected to significantly increase versatility and inter-operability between regional and global atmospheric models. At some later stage GF may be incorporated in the Earth System Modeling Framework (ESMF). The National Science Foundation (NSF) supports a portion of this project, including a graduate scholarship for a research assistant.

Description of Research
The so-called "globalization framework" refers to a general method for automatic expansion of regional atmospheric models to global coverage, that is, their conversion into the global models of the atmosphere. This objective is achieved through combined application of novel modeling tools (QU and VR grids) and modern information technology, including high-performance computing and communication (HPCC) and some elements of object-oriented programming design. QU grids (both conformal cubic and octagonal) provide a more homogenous distribution of computational points over the globe. Within this project the regional Eta model of the U.S. Weather Service is used for globalization

Accomplishments during the Reporting Period
The major modeling issues addressed in this period are treatment of the singular corner points on quasi-uniform grids and variable resolution on QU grids.

A series of simple linear advection experiments on the cubic grid were run to isolate and analyze the numerical problems related to treatment of singular points. In these experiments, a perturbation in the shape of a cosine bell is advected at constant speed around the sphere in such a way as to pass over singular corners. Two standard set of diagnostic curves show an uncharacteristic "bumpy" behavior that is a direct consequence of singularities—that is, uniqueness of these points and an accompanying sudden change (increase) of resolution in their vicinity. To solve this problem, the grid is modified close to the corners in such a way as to restore grid box parallelism. This technique successfully eliminates the problem and reduces sudden changes of resolution, but produces a small overlapping of three neighboring faces across the corners.

For the first time ever, the issue of variable resolution on QU grids was addressed by this research work. Three different techniques—grid stretching, grid overlapping, and Schmidt transforming—were compared on both cubic and octagonal grids. A new technique of grid overlapping addressed for the first time in this concept, shows the most promising results, but grid stretching remains the most practical choice for the time being [Rančić and Hai 2004].

There was some progress in developing the algorithm to cause the original Eta model to march in time. This progress was achieved by changing the order of execution for the adjustment terms. New theoretical and experimental evidence demonstrates the advantages of the new time-differencing sequence. In collaboration with Dr. Mesinger from the National Centers for Environmental Prediction (NCEP), these findings have been transferred to the operational regional Eta model.

One of the technical issues addressed in this period was an open source form of FORTRAN 95/90 programming that is now consistently applied through the modified Eta model code. Also, a message passing interface (MPI) version of communication libraries and the parallel I/O for QU grids that were developed and tested using

Compaq machine as the parallel computational platform at GSFC, were transferred (with small modifications) to a Beowulf cluster at UMBC. A global version of the Eta model step terrain and related logical masks on the B-grid were developed, and will be implemented in the dynamical core of globalization framework.

A UMBC graduate student, who joined the project at the beginning of 2002 through an NSF grant that provides partial support to this project, is now preparing his Ph.D. dissertation under the direction of the GEST investigator. Some important collaborations continued or were established through work on this project. Among them, the most significant is with Dr. Mesinger from NCEP, working to apply of some of the results of this research in the operational version of the regional Eta model, as noted above.

The conformal cubic and octagonal grids invented by the GEST investigator and widely advocated within this project are now used by at least five different groups around the world. These uses include a global atmospheric model developed by the Australian Weather Bureau, an oceanic model at NCEP, an atmosphere-oceanic climate model at MIT, and an oceanic and an atmospheric model associated with the Japanese Earth Simulator.

Dr. Rančić moved from GEST to the Joint Center for Earth Systems Technology (JCET) at UMBC during this reporting year.

Objectives for the Coming Year

The dynamical core of the globalization framework will be completed. Plans call for testing in idealized benchmark simulations and with real data; including physics and testing in seasonal-to-interannual climate mode; and possible coupling with an oceanic or surface hydrological model.

Task 930-03-068: **Science Information Systems**

GEST Investigator: Susan Hoban

Collaborators: Joe Bredekemp (PI, NASA), Nand Lal (GSFC), Linda Wilbanks (GSFC)

Abstract

Work under this task includes participation in NASA's Applied Information Systems Research Program and work with the Chief Information Officer (CIO) at GSFC on issues relating to information science and educational technology at GSFC. Activities include research and development in advanced technologies for NASA missions and science research programs. The GEST investigator also advises a master's degree student in the Computer Science and Electrical Engineering Department at UMBC.

Description of Research

With the data deluge produced by the advent of digital detectors and the increasing computing power available to scientists on their desktops and in centralized computing centers, there is a growing need for efficient and effective software tools to facilitate analysis, interpretation, and management of science data. This task seeks to study and support the development of such tools, particularly as they pertain to NASA's missions and scientific research programs. Of particular interest is the concept of a Virtual Observatory and related technologies, such as the Semantic Web and Fault-Tolerant Computing.

Accomplishments during the Reporting Period

The GEST investigator organized a workshop, held at Carnegie Mellon University in October 2003, for investigators in the Applied Information Systems Research Program (AISRP), and edited the workshop proceedings. Working with Dr. Ken Mighell of the National Optical Astronomy Observatories, the GEST investigator organized a workshop on Fault-Tolerant Computing that was held prior to the AISRP Investigators workshop, also in Pittsburgh, PA. Work with developers in Code 588 continues to devise a database-driven knowledge management system for use by researchers supporting NASA's missions and programs.

Other work addressed various issues relating to information science and technology at GSFC. This included participation in the Friends of Information Science (FIS) committee, which comprises of heads of information science and technology organizations at GSFC. The FIS coordinates such activities as the Information Science and Technology Colloquium Series and the Information Science and Technology Annual Achievement Award. The investigator continued to serve on the Backup and Recovery Study Team (BURST) that was constituted after the terrorist attacks of September 11. Center Director Al Diaz gave a GSFC Group Achievement Award to the BURST group; the civil servants on the BURST team enjoyed a cash award, and the GEST investigator enjoyed a piece of chocolate cake.

The investigator also serves on the master's degree committee of Mr. Somesh Kumar in the Computer Science and Electrical Engineering Department at UMBC.

Objectives for the Coming Year

A workshop for investigators of Applied Information Systems Research Program will be organized, and participation in the annual panel review will take place. A special session at the Information Technology and Computing Conference (ITCC 2004) will be organized, entitled "Space Science Computation and IT Applications", to be held in Las Vegas in April 2004. The GEST investigator will continue to serve on the CIO staff and on the FIS committee at GSFC. Development of a knowledge management system for NASA's missions and programs will continue.

Task 930-12-115: **PARAMESH**

GEST Investigator: Kevin Olson

Collaborator: Daniel Spice (PI, GSFC)

Abstract

The research conducted in the past year focused on developing and improving software for high-performance, parallel computer architectures. Specifically, this work has focused on maintaining and improving a software package known as PARAMESH. PARAMESH is a software package designed to give a user an easy route to parallelizing an existing structured mesh application. Also, work has focused on applying PARAMESH to several specific applications. These include collaboration with researchers at the Naval Research Laboratory to help develop a Flux-Corrected Transport magnetohydrodynamic (MHD) code with dynamic adaptive mesh capability. This code will be used to simulate Solar and magnetospheric phenomena. PARAMESH has also been successfully employed by a group at the University of Chicago for astrophysical applications, and is currently seeing wide application within that community. Finally, as a result of a collaboration with researchers funded by the NASA Earth Science Technology Office (ESTO) Computational Technologies (CT) project, PARAMESH has been modified to allow it to be used in radiation hydrodynamics models of gamma-ray bursts. PARAMESH versions 3.0 and 3.1 were released during 2003. Progress was also made in laying the groundwork for making PARAMESH an open source development project.

Description of Research

Use of large parallel computer architectures for scientific simulation purposes is not a straightforward exercise; it requires a great deal of expertise to write software that uses these machines in an efficient manner. The work performed over the past years has focused on this task to further develop and extend a software package known as PARAMESH. PARAMESH is a package designed to give an application developer who already has an existing serial code that operates using a logically Cartesian mesh. Further, the package provides a user with a dynamic, adaptive mesh refinement capability. PARAMESH handles all interprocess communication and load balancing automatically, while providing the user with a logical and simple

interface through callable Fortran 90 subroutines. PARAMESH is currently being used or is being planned for use in various applications in the Earth and space sciences, including simulating the Earth's magnetosphere, Solar coronal events, astrophysical X-ray bursts, Type I supernovae, gamma-ray bursts, galaxy cluster collisions, and gravitational waves.

Accomplishments during the Reporting Period

PARAMESH was extended and improved in two main areas. The first involves the addition of the capability to deploy PARAMESH as a precompiled library with which a user can link their application. Previously, PARAMESH required that a user set parameters in a configuration file and then compile PARAMESH along with their application. This is no longer necessary, as the user can now specify these parameters at runtime. This major extension of PARAMESH is now complete.

The second main area in which PARAMESH has been improved is the way in which it is managed. Over the past, year significant work has been done to allow other software developers to contribute to PARAMESH development. To this end, PARAMESH is now maintained using the Concurrent Versions System (CVS) on a machine at GSFC that others can access. A Web interface has also been set up to allow easier management of the development process.

The GEST investigator also participated—with an in-house team of scientists—in the Earth System Science (ESS) CT project. Support duties included participating in negotiations with several NASA-funded research groups selected under the Cooperative Agreement Notice (CAN) for this project. These negotiations led to collaboration being forged with one of these groups to aid in extending and using PARAMESH.

Objectives for the Coming Year

The main objective for the upcoming year is to add functionality to PARAMESH. This includes support for the HDF5 general purpose library and file format for storing scientific data, parallel data output, a C interface, support for different elliptic solvers, and incorporating PARAMESH into other software frameworks, such as Cactus, an open source problem-solving environment designed for scientists and engineers. Progress on PARAMESH has been severely limited because off-site developers cannot be monitored and managed in an efficient manner. Therefore, PARAMESH will be made an open source project, and its development will be managed from within GSFC by its original developers (the GEST investigator and P. MacNeice, of Drexel University) using the SourceForge Web site and supporting tools.

Task 935-01-022: **Parallel and Distributed Computing**

GEST Investigator: Udaya A. Ranawake

Collaborator: John Dorband (PI, GSFC)

Abstract

The Message-Passing Interface (MPI)-based parallel debugger was ported to the 512-processor Thunderhead PC cluster, and support for several FORTRAN compilers was added to the debugger. Two important climate models were ported to the PC cluster and benchmarks were run to evaluate their performance.

Description of Research

Work performed under this task addresses research and development of various software tools to facilitate the use of parallel and distributed systems. It also assists users to port and optimize large-scale scientific programs to run efficiently on these platforms.

Accomplishments during the Reporting Period

The MPI-based parallel debugger was ported to the Thunderhead PC cluster. The cluster consists of 512 Pentium 4 processors running at 2.4 GHz, interconnected by a fast network known as the Myrinet. The scalability of the parallel debugger was tested using several user applications. The

debugger was extended to include support for the Intel and Lahey Fujitsu FORTRAN compilers. The debugger is based on a client-server model. The server process is responsible for the graphical user interface that displays information to the user and handles user input. It also spawns client processes and communicates with them to receive data and status information and to send user commands. The client processes are spawned by the server using a binary tree algorithm, one per each MPI process and on the same node. Each client process spawns a native node level debugger as a subprocess that is attached to the corresponding MPI process. The client processes merely send commands from the server to the node-level debugger and forwards the output of the node-level debugger and its status back to the server. This model has resulted in a parallel debugger that scales to a large number of processors.

The debugger has an X-window-based user interface, which consists of four windows. One is the command window that provides a dialog box to accept user commands. It also contains some command buttons for commonly used debugger commands. The second window is the GNU Project Debugger (`gdb`) output window that is used to display the output of the gdb processes. The third is the source window, which is used to display the source line at which a process has stopped. Users can set or clear breakpoints by clicking on a line. Finally, the status window is used to display the status of the gdb processes, and is used to switch between the buffers displayed in the output window and the source window.

Several important climate models were ported and benchmarks were run to evaluate their performance on PC clusters. One such model was a coupled atmosphere and ocean model known as the Goddard Institute for Space Studies (GISS) ModelE program. ModelE currently runs on a single node of the cluster using one or two processors using the OpenMP application program interface (API), an open source multiprocessing parallel programming model. The program gave performance well when running on a single processor, but did not perform well when running on two processors, for reasons that have yet to be determined. The other ported model was the NASA-National Center for Atmospheric Research (NCAR) finite-volume General Circulation Model (fvGCM). The fvGCM program has a hybrid OpenMP/MPI-based parallel programming model. OpenMP is used to exploit parallelism at the node level on a multiple central processor system. MPI is used to handle interprocessor communication when the program runs on multiple computers (nodes) on a parallel computer system. The investigator benchmarked this program on the Thunderhead PC cluster to identify the bottlenecks and suggest ways to improve its performance.

Objectives for the Coming Year

As this investigator has left GEST, there are no objectives for the coming year.

Task 935-16-127: **Automatic Registration of Multi-Sensor and Multi-Temporal Remotely Sensed Imagery**

GEST Investigator: Harold Stone

Collaborators: Jacqueline Le Moigne (PI, GSFC,), Arlene Cole Rhodes (Morgan State University), Roger Eastman (Loyola College), Kisha Johnson (Morgan State University), Jeffrey Morisette (GSFC), Nathan S. Netanyahu (Bar Ilam and UMCP), Ilya Zavorin (GEST)

Abstract

Significant progress was made toward achieving fully automated image registration. Using Mars landing site imagery, a fully automatic procedure was demonstrated that successfully registered image pairs to within a few pixels. The image pairs presented an unusual challenge in that the relative displacements were on the order of hundreds of pixels. Since there is no Global Positioning System (GPS) on Mars, the imagery is

not accompanied by camera coordinates. Therefore, images cannot be preprocessed to be within a few pixels of displacement. The method developed under this task registers many small chips from one image with the second image, and uses Fourier-domain correlation techniques to find the best global match for each chip. This method proved fast and effective, and required no human intervention. This has significant advantages over pixel-domain searches, which are prohibitively expensive, even with coarse-to-fine multi-resolution when search regions are so large.

Description of Research

The thrust of the project is to register satellite imagery in various ways—multitemporal, multispectral, and multiplatform—to extract information that is not readily discernible in individual images. For example, high-precision registration of imagery taken at different times is often used for change detection. Cross-platform and cross-spectral registration can be used to classify regions by ground cover and land use. In earlier reports, varying degrees of success were described in registering both multitemporal and multispectral image pairs to within a few pixels' precision using a variety of registration techniques. In the best cases, the precision achieved was a fraction of a pixel. Multitemporal images from the same platform and from cross-platform images within the same spectral range register well, while cross-spectral image pairs yield mixed results.

Accomplishments during the Reporting Period

The highlight of the year was the registration of Mars image pairs that were to be used to select landing sites for the recent Mars Exploration Rover missions. The imagery does not contain camera coordinate data, so image pairs typically differ by large displacements. Earth imagery, on the other hand, has such coordinate data supplied through GPS tracking, and those coordinates are used in preprocessing the imagery so that image pairs are fairly closely registered before being subjected to high-precision registration.

The registration method consists of taking a grid of chips from one image and registering them a second image to find the position with the globally highest normalized registration. Using a least-squares optimization program, the algorithm computes the coordinates of the rigid transformation that best characterizes the X positions. Then the rigid transformation is applied to the positions of the original chips. The displacement of each X from the corresponding calculated value gives an indication of registration error. Registration errors have been observed to follow an obvious wave pattern whose structure can probably be traced to optical distortion or distortion due to elevation. In principle, the distortion can be modeled and incorporated into the registration process to eliminate that source of error.

Objectives for the Coming Year

More work with Mars imagery will be done, where the Fourier-domain correlation technique has unique advantages for image registration. Other work will continue detailed comparative studies of registration algorithm performance on Earth imagery applications. The studies are designed to reveal such characteristics as range of convergence, registration precision, and computational complexity.

Task 935-19-124: **Automatic Registration of Multi-Sensor and Multi-Temporal Remotely Sensed Imagery**

GEST Investigator: Ilya Zavorin

Collaborator: Jacqueline Le Moigne (PI, GSFC)

Abstract

Work under this task investigates how various feature extractors, search techniques, and similarity metrics can be combined to produce reliable results when applied to multisensor data that have previously been systematically corrected. The class of geometric transformations was expanded by including isometric scaling, which allowed images of different resolutions to be more precisely registered. A fast iterative gradient-based search strategy was adapted to the problem of satellite image registration. Also, a new method was devised to evaluate registration algorithm performance using various types of test data.

Description of Research

Image registration can be viewed as a sequence of two steps. First, image features are extracted from the original data. Then, using the given search strategy and similarity measure, the search space is traversed to find the best match. The previous focus was on determining the most robust type of image feature in terms of subpixel registration using exhaustive search as the simplest possible approach. Misalignment between images was assumed to consist only of rotation and translation; exhaustive search through a discretized mesh of these parameters was used to find the best match.

Accomplishments during the Reporting Period

The recently developed Mutual Information (MI) gradient-based registration method was adapted to satellite image registration to handle radiometric differences significantly better than by using an L2-based approach. Adding images from other platforms expanded the test image database, and various algorithms developed by the Registration Group were evaluated using the new data. The testing methodology was evaluated by using more sophisticated point spread function (PSF)-based methods for synthetic image generation, and by establishing a way to assess the accuracy of the triangularization method applied to real data.

Objectives for the Coming Year

As the investigator as left GEST, there are no objectives for the coming year.

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Hydrological Science Research Group

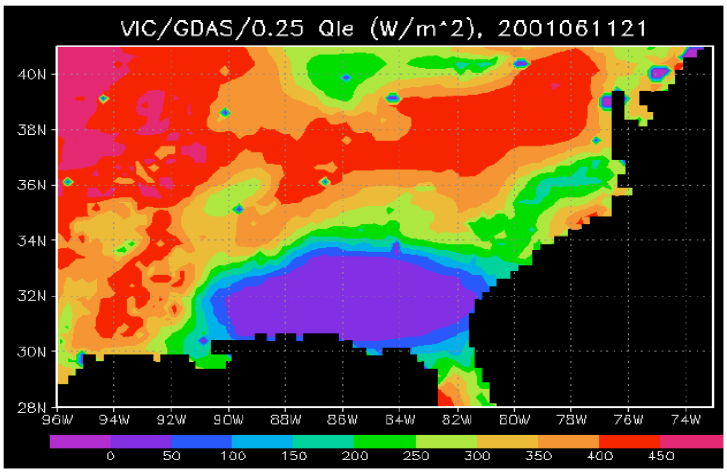

Figure 1. *Estimated latent heat flux from the Variable Infiltration Capacity (VIC) model at 21:00 hrs GMT on 11 June 2001 over southeastern U.S. at 0.25 x 0.25 degree grid cell spatial resolution. The model was forced using GDAS data.*
(Courtesy of Sujay Kumar and the LIS Project)

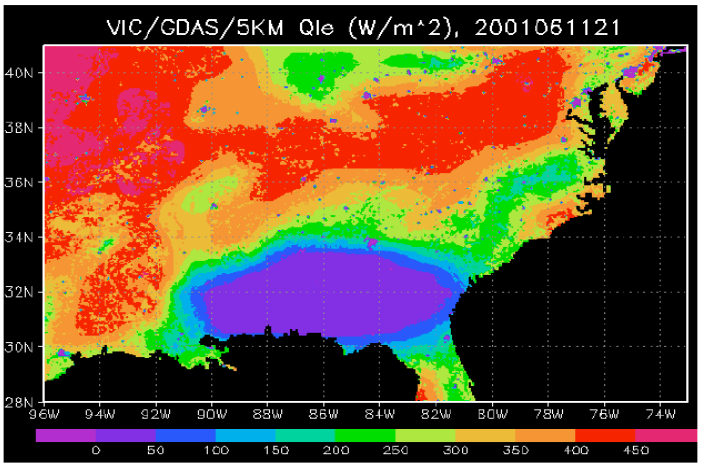

Figure 2. *Same as Figure 1, but for 5 x 5 km grid cell spatial resolution*
(Courtesy of Sujay Kumar and the LIS Project)

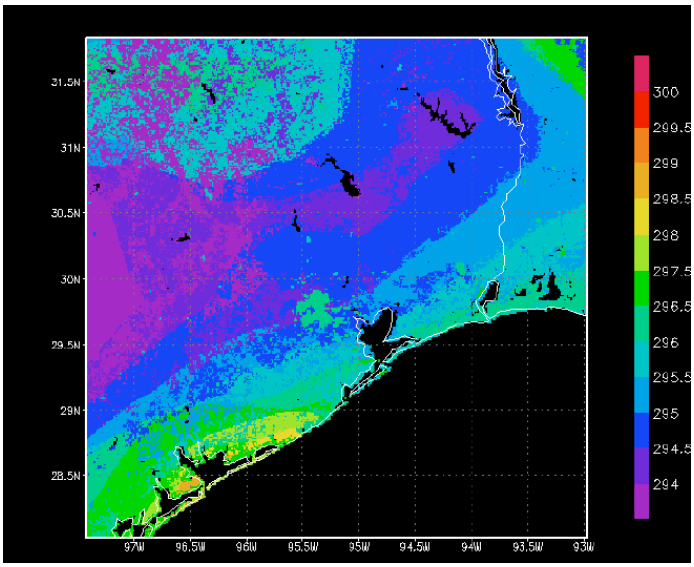

Figure 3. *Surface Temperatures on 22 August 2002 at 15:00 GMT for an area near Houston at 1 x 1 km grid cell spatial resolution*
(Courtesy of Sujay Kumar and the LIS Project)

Hydrological Sciences Research Group

The GEST Hydrological Sciences Research Group integrates research into the terrestrial hydrosphere and oceans with studies of the atmosphere, geosphere, and biosphere. The group studies a wide variety of Earth surface and near-surface processes, including surface hydrology dynamics and their interactions with climate, and oceanography components and their link to climate variability. The research is conducted in the context of Earth System Science, and is performed within observational and modeling frameworks. For example, one of the largest efforts in the group is that of land surface state modeling. This effort integrates remote sensing data of different land surface variables with land surface physical model outputs (such as soil moisture models). The integration is achieved through data assimilation methodologies and advanced computational technologies, and the final land surface representation can be used to initialize numerical models of global climate. By taking such holistic approaches, the group seeks to acquire and integrate a diverse set of remote sensing, model, and field measurements over a range of different spatiotemporal scales to enhance our understanding of physical processes and, perhaps, improve our ability to predict future Earth system changes.

Research on terrestrial hydrosphere-biosphere-atmosphere interactions has continued to advance within the group. A major element of this effort is through land surface model (LSM) implementation at regional and continental scales. Both the National Land Data Assimilation System (NLDAS) and its global counterpart (GLDAS) are maturing well. These systems use global and regional satellite and ground-based observing systems that are coupled to a land surface modeling framework to produce optimal fields of land surface states, and energy and water fluxes. The next-generation system, the Land Information System (LIS), is also in advanced stages of development, and uses high-performance computing to increase modeling resolution in terms of both space and time discretization. For example, the LIS initiative is attempting to model terrestrial water cycle components on a spatial grid of 1 km x 1 km. This is a finer scale than either the LDAS of NLDAS LSMs. Computationally, the LIS project is a very demanding activity that is succeeding in significantly increasing efficiencies in computational power by parallelizing the model environment.

Several group members are involved with the Earth System Science LSM effort from the perspective of computer science technology from the perspective of hydrological science application. The functionality of the LSMs has improved to the point that science studies are now being conducted. For example, progress has been made in determining the effect of the North American Monsoon on land surface state predictability, a topic that can only be investigated through the use of continental-scale LSMs. The LIS project has demonstrated the advantage of estimating water and energy fluxes at relatively fine spatial resolutions. It has shown how engineered surfaces (*e.g.,* buildings, roads, parking lots, etc.) can affect mesoscale land-atmosphere interactions, including water, energy, and momentum fluxes. Observation-based data and products from some of the new generation of satellite instruments (*e.g.,* Aqua and Terra) are also starting to be examined for their utility in these modeling schemes. For example, soil moisture estimates from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) on the Aqua platform is being evaluated to determine its appropriateness for data assimilation into LSMs. Other sources of data are also being assessed for their utility in forcing these LSMs, notably various precipitation products from models, satellite observations, and reanalysis sources.

A second major theme in the Hydrological Sciences Research Group addresses the utility of state-of-the-art satellite observations from EOS and heritage satellite systems in addition to newly developed instrument systems for the estimation of key hydrological variables. Progress has been made in developing methods to better estimate global snow mass and soil moisture using AMSR-E data. Much of this work has focused on defining the uncertainties associated with the estimation of these variables. Operationally, this is a very challenging task. In ocean and near-shore studies, airborne lidar remote

sensing is being used for phytoplankton biomonitoring and another study is concerned with the investigation of sea surface salinity using Aquarius (a planned Earth System Science Pathfinder mission). The correction of biases in TOPEX and Jason-1 data is also an important part of the group's activity, resulting in advances in understanding the role of Arctic climate in the global climate system. Our understanding of these different variables in the global energy and water cycle systems will increase with these exciting product developments derived from the next generation of advanced technology Earth observing instruments.

The overlapping science issues encountered throughout the Hydrological Sciences Research Group are accompanied by common technical themes that weave through these studies, such as data manipulation, visualization and storage issues, remote sensing techniques and the continual need to assist with new instrument concept developments, and field campaign planning concerns. While the Hydrological Sciences Research Group is diverse in its scope, these common technical themes and our interdisciplinary approaches to investigating regional and planetary-scale processes help highlight our common interests. Furthermore, research into land and hydrospheric processes has become such an important issue across NASA that members in this group are tasked with coordinating and implementing NASA's Global Water Cycle research initiative. This is a truly interdisciplinary effort to integrate broad-based hydrological science research both within NASA and in the wider scientific community. Successful implementation of this initiative should facilitate better understanding of land surface states, and ultimately will help us better predict hydrological cycle state variations.

Richard Kelly

Task 971-20-137: **Aquarius Sea Surface Salinity**

GEST Investigator: S. Daniel Jacob

Collaborators: Chester J. Koblinsky (PI, GSFC), Sirpa Häkkinen (GSFC), David Levine (GSFC), Nick Shay (University of Miami), George Halliwell (University of Miami)

Abstract

The primary focus of this research is on sea surface salinity and ocean mixing. Numerical simulations and observational research have led to understanding and quantification of sea surface salinity (SSS) variability due to surface forcing changes. Oceanic mixing has also been shown to affect SSS evolution. These contribute to changes in the mean ocean state in addition to meridional heat and freshwater transports in the ocean. As part of a secondary effort, mixing parameterizations generally used in the ocean component of the coupled ocean atmospheric tropical cyclone intensity prediction system were shown to introduce significant variability in simulating the upper ocean heat content. Multiple schemes were evaluated by comparing simulations with observations.

Description of Research

Oceanic fresh water transport has been shown to play an important role in the global hydrological cycle. With more than 70% of global evaporation and precipitation occurring over world's oceans, small changes in these parameters could cause major changes in the terrestrial water budget. SSS is representative of surface fresh water fluxes; the upcoming NASA Earth System Science Pathfinder (ESSP) Aquarius mission will provide excellent spatial and temporal SSS coverage to better estimate the net transfer. However, SSS is also controlled by advection and mixing processes; therefore, as part of the Aquarius science team, the GEST investigator conducts numerical simulations to understand and quantify various mechanisms controlling SSS in relation to surface freshwater fluxes over seasonal and interannual time scales. The second effort led by the GEST investigator focuses on identifying the most appropriate oceanic mixing parameterization for use in coupled predictive models of hurricane track and intensity. *In situ* and remotely sensed data are used to evaluate and identify different mixing parameterizations in hurricane-forced numerical models in collaborating with scientists from the University of Miami Rosenstiel School of Marine and Atmospheric Science.

Accomplishments during the Reporting Period

In nature and in coupled models, ocean-atmosphere feedbacks of freshwater are mutually compensated by evaporation and precipitation. However, in standalone ocean general circulation model (OGCM) studies, precipitation is prescribed from forcing/flux data sets, and evaporation is determined based on a variety of surface boundary conditions. Sea surface temperature and salinity evolution depend upon these boundary conditions, through which water mass formation and thermohaline circulation are affected in OGCM simulations. In general, however, in most OGCM simulations, only one of the many forcing/flux datasets is used in combination with one or few surface boundary conditions, the choice of which depends on the availability and personal preference. Although individually these data sets have been carefully calibrated and adjusted for balanced fluxes, standard deviations of annual mean precipitation and evaporation field for an ensemble of six data sets exceed 500 and 250 mm/yr, respectively. Additionally, the choice of vertical mixing parameterization representing subgrid scale (SGS) processes in the ocean also introduces variability in OGCM simulations. Significant effort was devoted to investigate these issues by using a numerical model. A massively parallel version of the hybrid coordinate ocean model configured in a near-global domain (extending from 40° S to 65° N) at 2° resolution at the Equator on a Mercator grid was implemented on the GSFC Compaq SC45 super cluster. Over 20 simulations were conducted.

The model initialized from Levitus climatology was integrated for 30 years to near dynamical equilibrium for two forcing (University of

Wisconsin, Madison, and Southampton Oceanographic Center) datasets. Runoff for approximately 800 rivers in the domain was prescribed using a monthly climatology. The domain-averaged temperature and salinity profiles show a steady drift of the model ocean to a warmer and more saline state for SOC forcing, while for UWM forcing there is a freshening trend, accompanied by less-rapid warming. Compared to the annual mean Levitus climatology, simulated SSS remains fresher, compensated by sea surface temperature increases for the UWM forcing case. These fields at the end of year 30 are used as initial conditions for establishing the sensitivity of SSS to various SGS mixing parameterizations.

The model was integrated for an additional five years with UWM forcing, using four vertical mixing parameterizations. The volume-averaged temperature and salinity values indicated the divergence of the simulated ocean state. Based on a three-year mean, maximum variability in SSS among the four schemes occurs generally in the near-equatorial region, where precipitation is also high. Large differences are found in the near-equatorial Atlantic and the Indian Oceans between the schemes year around. These results indicate that the variability induced by both forcing and sub-grid scale mixing parameterizations have SSS signatures three to six times greater than the Aquarius measurement accuracy specification. Aquarius SSS measurements therefore should help to close the oceanic fresh water budget. These results provided the baseline variability estimates for responding to the ESSP Aquarius Risk Mitigation Phase Task, and were included in the final report. A live access server (LAS) was set up on the Web at http://aquarius1.gsfc.nasa.gov:8080/las/servlets/dataset to host many of the available flux data sets.

As part of the National Oceanic and Atmospheric Administration (NOAA)-sponsored project on upper ocean mixing parameterizations, two configurations of the Hybrid Coordinate Ocean Model (HYCOM) were set up to simulate upper-ocean response during hurricanes Gilbert (1988), Isidore (2002), and Lili (2002). Initial conditions for Gilbert case were derived from extensive *in situ* observations of temperature and salinity. For Isidore and Lili, the initial fields are derived from the standard Atlantic HYCOM simulations. Initial comparisons of the simulated vertical structure with the expendable profiler data acquired from the NOAA P3 Hurricane Hunter aircraft as part of NOAA/National Science Foundation (NSF) U.S. Weather Research Program (USWRP) indicate good agreement with observations. By combining large-scale three-hourly 10-m winds from the basin-scale HYCOM with winds from aircraft and buoys, boundary layer forcing was derived. Effects of rainfall on the upper ocean heat and salt budgets were investigated.

Objectives for the Coming Year

Modeling of the SSS variability for different forcing data sets and its impact on oceanic thermohaline circulation will be continued in the coming year. Due to the coarse resolution of the near-global model, the magnitude of oceanic current systems are biased lower; therefore, estimates of the relative magnitudes of advection, mixing, and surface fluxes will be intrinsically biased. Consequently, future research will use high-resolution limited area models to investigate the relative roles of these mechanisms in mixed-layer evolution. More-realistic forcing data sets, based on remotely sensed data, will also be used in these simulations, with three higher-resolution sub-domains in the Atlantic, Pacific, and Indian Oceans. Ocean response studies will be conducted for Hurricanes Gilbert, Isidore, and Lili to evaluate different mixing parameterizations and to identify the scheme that performs well when compared with data. Using data from Argo profiling floats, a new activity to relate steric height anomalies to the surface height data derived from altimeter observations will begin. Based on this approach, geostrophic baroclinic heat and mass transports will be quantified in the North Atlantic and then extended to other oceans.

Task 971-26-149: **Early Spring Bloom in the North Atlantic Associated with NAO-Induced Long-Term Oceanic Circulation Changes**

GEST Investigator: Ken-ichi Mizoguchi

Collaborators: Watson Gregg (PI, GSFC), Sirpa Häkkinen (GSFC)

Abstract
Results from a control simulation of a coupled ice/ocean/biogeochemical model that covers the Arctic and North Atlantic Oceans were compared to the chlorophyll fields from satellite-derived ocean color measurements, and validated. To understand North Atlantic Oscillation (NAO)-induced long-term variability associated with spring chlorophyll in the North Atlantic, two numerical simulations, with low- and high-NAO atmospheric forcing, were performed. The timing of the model produced spring blooms in both the high- and low-NAO cases, as identified in SeaWiFS and CZCS satellite measurements. Temperature changes appear to be associated with the timing of the spring blooms.

Description of Research
To investigate NAO-related long-term changes in the primary productivity, three numerical experiments were carried out in this study. A coupled ice/ocean/biogeochemical model of the Arctic and North Atlantic Ocean is forced with the atmospheric forcing decomposited from the control and the high and low phases of the NAO. It was assumed that long-term ocean circulation changes associated with the different phases of the NAO directly impact the ecosystem in terms of the spring bloom. The ice/ocean model is a fully prognostic three-dimensional primitive-equation model, based on the Princeton Ocean Model (POM). The ice/ocean model is forced for 20 years with atmospheric climatological data. The output from the end of the twentieth year is used as an initial field for the coupled ice/ocean/biogeochemical model. The biogeochemical model is coupled to the ice-ocean model, and contains four phytoplankton functional groups (*i.e.,* diatoms, chlorophytes, cyanobacteria, and coccolithophores), four nutrients (*i.e.,* nitrate, ammonium, silica, and dissolved iron), a single herbivore group, and two detrital pools. The coupled ice/ocean/biogeochemical model is integrated with the atmospheric forcing described above for 20 years. The model is then integrated for an additional five years. In addition to the control simulation, two additional numerical experiments were carried out, using the atmospheric forcing decomposited from years with high and low NAO index values. The biological component of these simulations remains the same as that of the control simulation; the high- and low-NAO runs differ only in the atmospheric forcing fields. Starting from the initial 20-year run of the control simulation, the high NAO and low NAO cases were integrated for an additional 5 years.

Accomplishments during the Reporting Period
The model validation case using the control simulation shows that the results are more or less the same as those obtained from previous studies. The low- and high-NAO cases succeed in simulating the timing of the observed spring blooms. The bloom times are associated with increased diatom and chlorophyte populations in the low-NAO case relative to the high-NAO case. The difference in the timing is primarily controlled by temperature variations during the growing season. The relatively warmer temperature in the low-NAO case produces a favorable condition for the phytoplankton to grow much earlier.

Objectives for the Coming Year
Upcoming work will focus on the connection between biological productivity and oceanic decadal cycles. To investigate the links between biology and ocean dynamics, numerical experiments with interannually varying forcing will be conducted.

Task 971-32-161: **Air-Sea-Ice Interaction**

GEST Investigator: Yunhe Zhao

Collaborator: Antony K. Liu (PI, GSFC)

Abstract

Understanding sea-ice motion dynamics in the Arctic summer has improved by using NASA's Advanced Microwave Scanning Radiometer-EOS (AMSR-E) 89 GHz brightness temperature data. The combined use of two similar satellite datasets (*i.e.,* from QuikSCAT and SeaWinds) has also reduced the error of sea-ice tracking results when compared with the results from only QuikScat or SeaWinds data alone. A nonlinear internal wave model has been extended to include a shoaling term, and the numerical simulations using synthetic aperture radar (SAR) data in deep water as an initial condition have produced wave evolution phenomena on the continental shelf that agree reasonably well with mooring measurements at a downstream station. Principal component analysis (PCA) has been carried out on both pressure field data and satellite-derived sea-ice motion in the Arctic to study the effects of wind and the Arctic Oscillation (AO) on sea-ice motion.

Description of Research

This research focuses on satellite ocean remote sensing data analysis and imaging processing, especially by wavelet analysis of satellite data from the Special Sensor Microwave/Imager (SSM/I), QuikScat, SeaWinds, and AMSR-E for sea-ice motion, deformation, and dynamics in the Arctic. The objectives are to develop effective and efficient algorithms to derive sea-ice motion and deformation using satellite data for sea-ice dynamics and joint research on climate variability study based on these data sets. These results will be used to study environmental effects on sea-ice dynamics, and to further understand physical processes in the Earth's climate system.

Accomplishments during the Reporting Period

Two new satellite data sets, from AMSR-E and SeaWinds, became available in the reporting period. Efforts were made to characterize the new datasets and to modify the ice-tracking algorithm to use it with the new datasets, with the expectation that the high resolution of AMSR-E 89 GHz data will improve the sea-ice tracking results. It was also thought that SeaWinds and QuikScat data could be combined to enhance the signal-to-noise ratio to improve the ice tracking results because of their similar characteristics. Results have shown that this expectation has been confirmed. Because of the high resolution of the AMSR-E data, and use of a novel preprocessing technique, the sea-ice tracking method applied to the Arctic during summer months gives reasonably good results. This is the first time that good sea-ice motion data have been derived from a satellite dataset in the Arctic during summer months. For SeaWinds data, because SeaWinds and QuikScat data have similar characteristics and properties, the combined use of these two satellite data have reduced the error of the sea-ice tracking results when compared with the results from either QuikScat or SeaWinds data alone. The high resolution of AMSR-E data has also allowed derivation of higher-resolution sea-ice motion in a localized area. In addition to the new datasets, daily sea-ice motion in the Arctic, obtained using QuikScat data, is routinely derived. Principal component analysis (PCA) has been carried out on both pressure field data and satellite-derived sea ice motion in the Arctic from December-March, to study the effects of wind and the AO on sea-ice motion. Preliminary results indicate that the first two principal components of sea-ice motion are not correlated with AO index time series. Studies in this area are continuing.

A large effort has also been devoted to develop a numerical simulation of internal waves in deep water using a nonlinear internal wave model, and to use SAR data in deep water as an initial condition. The nonlinear internal wave model has been extended to include the shoaling term, and the numerical simulations have produced wave evolution on the continental shelf that agrees well with mooring measurements obtained at the downstream station.

Objectives for the Coming Year

With the preliminary success of deriving sea ice motion in the Arctic during summer months using AMSR-E 89 GHz data, the sea ice tracking procedure for the summer months will be refined to produce more complete and more accurate summer sea-ice motion from AMSR-E and other satellite data for the Arctic. A joint wind drag parametric study is planned in the Okhotsk Sea with a researcher from the Navy. The sea-ice tracking procedure for deriving sea-ice motion in the Okhotsk Sea from satellite data will be optimized, and sea-ice motion in the area will be derived from QuikScat and AMSR-E data. The ice tracking results will then be used in a numerical model. Studies of the effect of changes in atmospheric circulation on patterns of sea-ice motion and deformation will continue, using the sea-ice motion and deformation data derived from QuikScat, SSM/I, AMSR-E and SeaWinds data.

Task 972-21-143: **Advanced Laser Fluorescence Technologies for Oceanic Biomonitoring**

GEST Investigator: Alexander M. Chekalyuk

Collaborators: John Gerlach (PI, GSFC), Frank Hoge (GSFC/WFF), Steve Bailey (GSFC)

Abstract

Several new laser fluorescence excitation/emission techniques and instruments were developed and tested under laboratory and field conditions. These developments provided improved assessments of chlorophyll *a* (Chl-*a*) and accessory pigments, phytoplankton physiological status, phytoplankton characterization, and identification of dominant algal groups. The shipboard and airborne tests were conducted in a wide range of bioenvironmental conditions in the Delaware River, Chesapeake and Delaware Bays, and the adjacent areas of the Middle Atlantic Bight. The laser analytical data were confirmed by independent measurements with well-established techniques, including high-performance liquid chromatography (HPLC) and optical microscopy. The potential to assess phytoplankton physiology and photosynthetic activity from spaceborne measurements of natural fluorescence was evaluated. The feasibility of using active satellite light detection and ranging (lidar) measurements of pigment florescence was analyzed.

Description of Research

The research conducted under this task focuses on two major goals. One is to develop new laser fluorescence techniques for advanced phytoplankton pigment and taxonomic analysis; the second is continuing research on superactive pump-and-probe (P&P) lidar technique for airborne remote sensing of phytoplankton physiology in the ocean and coastal areas. Research activities include theoretical analysis, laboratory studies, instrument development, and airborne and shipboard field measurements. New technological developments address spatial and temporal variability of marine ecosystems, their driving forces and impacts; biological carbon sources and sinks in the ocean; natural and human environmental impacts and their consequences in coastal areas; and spatiotemporal gaps in satellite validation/calibration over meso- and synoptic scales.

Accomplishments during the Reporting Period

New techniques for laser-induced fluorescence analysis of phytoplankton were tested during a ship/airborne experiment conducted in the Chesapeake and Delaware Bays in October 2003. Three instruments that were developed in house, the Laser Phytoplankton Analyzer (LPA), the Laser Excitation/Emission Matrix Fluorometer (LEEM), and the Shipboard Laser Fluorometer (SLF) were deployed on the *R/V Cape Henlopen*. Significant spatial variability in phytoplankton assemblage composition, photosynthetic pigment concentrations, and phytoplankton physiology was observed in the ongoing LPA measurements, later confirmed by laboratory sample analyses with HPLC and optical microscopy. The use of advanced fluorescence emission measurements (FEM) and supporting data processing protocols resulted in a significant improvement in the accuracy of Chl-*a* concentration assessment. In addition, a new FEM technique was tested for

concentration measurements of alloxanthin, a pigment biomarker of cryptophytes, an ecologically important class of phycobilin-containing species. The observed extremely high correlation between total content of photosynthetic carotenoids (PSC) and Chl-*a* concentration, if confirmed globally, justifies the use of green laser excitation at 532 nm in current airborne and, potentially, future satellite lidar fluorosensors. The shipboard SLF measurements were used to bridge the spatiotemporal sampling gap between the HPLC and Airborne Oceanographic Lidar (AOL) measurements, and to derive new relationships for improved assessment of pigment concentrations from AOL FEM measurements in coastal and estuarine waters.

A laser fluorescence excitation (FEX) technique was used to retrieve additional information for pigment and taxonomic characterization of phytoplankton. A theoretical deconvolution analysis and cruise field measurements indicated feasibility of laser FEX concentration estimates for two important accessory pigments, chlorophyll *c* (Chl-*c*) and chlorophyll *b* (Chl-*b*). High correlation between the LPA FEX measurements and corresponding Chl-*c* and Chl-*b* HPLC assessments were observed in areas of significant Chl-*c* and Chl-*b* abundance. The combined FEX/FEM measurement protocol was also used for laser identification of dominant phytoplankton groups, diatoms, and cryptophytes.

The laboratory and field LPA tests provide a basis for further technological advancement aimed at operational use for laser bioenvironmental monitoring in coastal and estuarine areas, including remote sensing applications. To evaluate the feasibility of acquiring airborne FEX/FEM measurements, a new prototype airborne lidar system was developed and successfully tested in the Chesapeake Bay and Middle Atlantic Bight in October 2003. The new system incorporates two major technological advances: an optical parametric oscillator (OPO) for wavelength-tunable remote fluorescence excitation (410-670 nm) and an intensified charge-coupled display (CCD) spectral camera for hyperspectral analysis of the backscattered lidar signal (400-800 nm). Six excitation wavelengths were tested during the airborne FEX/FEM missions. Diatoms/dinoflagellates and cryptophytes were identified as dominant algal groups in the middle and lower portion of the Chesapeake Bay.

The 2003 activities dealing with airborne P&P lidar assessment of phytoplankton physiology and photosynthetic activity largely focused on advancing data processing and analysis techniques to further optimize measurement protocols and to formulate requirements for operational use of the P&P technology. A biophysical model of diel chlorophyll fluorescence efficiency (CFE) photoregulation was developed for quantitative assessment of phytoplankton physiological status over synoptic and regional scales in high-latitude areas that play an important role in global biogeochemical processes. The feasibility of estimating primary productivity from Moderate Resolution Imaging Spectroradiometer (MODIS) fluorescence data products that account for variability in photosynthetic quantum yield was also evaluated. A time-resolved, low-light measurement protocol was proposed for future missions to fully explore the potential of spaceborne measurements of natural fluorescence for global assessment of phytoplankton physiology and primary productivity. The potential for conducting such measurements with a Moon-based Earth observing system was analyzed.

Objectives for the Coming Year

Work will continue to develop new laser analytical methods and data processing algorithms. Evaluation of the new technological potential in coastal studies, environmental surveys and satellite validation will continue, and field laser measurements will be conducted in the Chesapeake and Delaware Bays, the Middle Atlantic Bight, and coastal areas of South Carolina.

Task 972-37-169: **Empirical Algorithm Refinement for TOPEX/Poseidon and Jason Altimeter Sea-State Bias Range Correction by Using Operational Global Wave Model Data**

GEST Investigator: Hui Feng

Collaborators: Douglas Vandemark (PI, GSFC/WFF), Brian Beckley (Raytheon/ITSS), Janet Campbell (University of New Hampshire), George Hayne (GSFC/WFF), Pat McCormick (Hampton University)

Abstract
Research under this task is designed to improve our understanding of the impact of ocean surface waves on global ocean surface topography measurements obtained by ocean altimetry. The work also focuses on developing an improved empirical sea-state bias (SSB) algorithm by adding operational global surface wave model data, for which the wave model is forced by high-resolution wind forcing fields from scatterometry. Specific strategies to potentially refine SSB correction algorithms that were proposed have been in progress for the last year. Preliminary results suggest that the combination of altimeter, scatterometer winds, and surface wave model data offer more informative data than other approaches, and may lead to improvement of empirical SSB estimates.

Description of Research
Current operational SSB algorithms are based on two altimeter-derived variables: the surface wind speed, and ocean-surface significant wave height (SWH). The residual sea-surface height remains within ~1% of SWH. The latest theoretical studies and field observations have clearly indicated the long wave orbital velocity (m2) and short-scale slope variance (m4) that describe the sea state's degree of steepness and nonlinearity are directly driving SSB variability. In current SSB algorithms, the altimeter-derived wave height and wind speed do not fully resolve the surface wave steepness and nonlinearity. Future improvement in SSB corrections should be linked to these high-order surface wave parameters. Because spatiotemporal scales of the ocean surface wave field span 1-200 km and 0.5 - 48 hrs, and operational surface wave models are able to provide a full 2-D wave spectral estimation at specified spatiotemporal scales, global validation of a SSB correction algorithm refinement may require use of a global surface wave model, as few approaches exist to obtain such high-order wave parameters from satellite platforms.

Accomplishments during the Reporting Period
In the past year, the third-generation wave model (WaveWatch III), developed by the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and the National Centers for Environmental Prediction (NCEP), was implemented, and used to complete the generation of six-hourly global wave parameter fields, including high-order spectral parameters for surface waves for the year 2000. The wave model was driven with two different wind-forcing fields, both from high-resolution NCEP/QuickScat products and from the NCEP model, to assess the value of QuickScat wind forcing data in evaluating SSB. The operational wave model-derived wave parameters and wind products were all coregistered with valid deep-ocean TOPEX measurements for the year 2000. The data combination has led to a dataset of more than 1.5 million altimetry samples for that one year, each containing more than 20 parameters related to the nearly concurrent measurements of altimetry, surface waves, and surface winds. Wave outputs from different wind forcing inputs have been processed and collocated in the same way. Preliminary results have shown a clear difference in model output, from significant wave height through higher-order wave parameters, driven by the different wind fields. For instance, a global comparison of the two wave products shows that RMS wave slope probability density function (pfd) from NCEP/QuickScat wind forcing more closely resembles that from the National Data Buoy Center (NDBC) buoy climatology than the product from NCEP model winds. As a result, the

scatterometer-observed winds are thought to be critical for the SSB studies.

In addition to the completion of global wave model implementation and data generation, the second component under this task includes analysis of TOPEX waveform data. The objective is to propose a reasonable approach to retrieving one more "geophysical" parameter (*i.e.,* elevation skewness) from waveform fitting in addition to the first-order SSB signals, to improve the SSB correction. Noise reduction processing and a waveform piecewise-fitting scheme have been implemented. These permit one to focus on the signals in the leading edge that can be decomposed to provide significant wave height, elevation skewness, and track-point position of the waveform's amplitude; the signals in the trailing edge represent only the off-nadir angle.

Objectives for the Coming Year

Work in the coming year will focus on the higher-order moments of m2 and m4, which describe wave steepness and are critical for SSB studies. The hypothesis that the wave model driven by high-resolution spectral and spatial wind forcings provides more precise/realistic estimates of the high-order wave parameters will be tested. Some oceanic NDBC buoy data will be selected and collocated with a compiled dataset to calculate the high-order wave parameters for validation, a critical step for further algorithm development. A third objective is to continue to run the operational wave model to extend the volume of the TOPEX wave model and wind dataset to four years (to 2004), and to build a similar dataset for Jason-1 for the years 2001-2004. Finally, it has been proposed that a neural network approach should be adopted and implemented under the direct sea-surface height anomaly (SSHA) analysis as a statistical tool to identify one more critical wave parameter from the compiled dataset in addition to altimeter-derived surface wave height and wind. The key efforts for this component are to define a set of metrics to potentially identify one or two parameters derived from the operational wave model. Extensive neural network training will be designed and processed to help parameter identification, and the identified parameter will be provided as ancillary input to an improved SSB correction algorithm.

Task 974-03-070: **Coordinating and Implementing NASA Global Water Cycle Research**

GEST Investigator: Deborah Belvedere

Collaborators: Paul Houser (PI, GSFC); Pierre Morel (GEST [retired]), Robert Schiffer (GEST)

Abstract

This activity, based at GSFC, supports scientific collaboration and coordination for NASA's global water and energy cycle research. Specifically, planning task forces, consisting of NASA scientists and researchers from the broader scientific community, have been assembled. These task forces have produced and enabled implementation plans that address NASA's Earth Science Enterprise (ESE) strategies, and address the emergence of crosscutting water cycle research initiatives developed by interagency, government, and administrative science panels.

Description of Research

Considerable attention has been given to the importance of the global water and energy cycle in assessing the consequences of natural and human-induced climate change. In particular, the U.S. Global Change Research Program (USGCRP) *Plan for a New Science Initiative on the Global Water Cycle* and the subsequent National Research Council response have identified the global water cycle as a critical research theme necessary to advance climate-change research in the coming decades. More recently, the current administration's Climate Change Science Program (CCSP) has identified the water cycle as a critical crosscutting theme that all science agencies must address in a coordinated and optimized synergistic fashion. Therefore, the challenge faced by NASA and other government research agencies is to construct an ambitious, focused, and coordinated implementation plan that will significantly

advance our understanding of—and predictive capabilities within—this crosscutting, scientific theme specifically, and climate-change science in general.

Accomplishments during the Reporting Period

Generation of four large water and energy cycle documents has been undertaken by researchers and assistants in relevant groups. Work to bring these documents to publication was accomplished through weekly teleconferences, organized meetings, and collaborative creation of new graphics and documents. The Goddard Water and Energy cycle theme document is nearing completion; it will provide a substantial overview of all research activities pertaining to water and energy cycle in the GSFC Earth Sciences directorate. Among other results, this effort will provide information needed for hiring. A NASA Energy and Water Cycle Study (NEWS) NASA Research Announcement (NRA) has been written and is currently under review at NASA HQ, for release in 2004; this will be followed by a NEWS implementation plan. The NEWS NRA and long-term implementation strategy for the NASA HQ Science Division would consist of a core project, science team members, and NRAs that would solicit the contributions and collaborations of the community-at-large. Finally, a Global Energy and Water Cycle Experiment (GEWEX) Americas Prediction Project (GAPP) implementation plan and brochure was written and distributed for review. Participation in advertising for (and review of) candidate hires for work in water and energy cycle projects and in other fields was undertaken. Other contributions included field work for the Cold Land Processes Experiment project, the goal of which is to measure the water content of snow from space using satellite remote sensing.

Objectives for the Coming Year

The final version of the NEWS implementation document will be distributed to the scientific community and to NASA (and other government research agency) managers. Support will continue for relevant NASA HQ water-cycle program activities and potential core projects and community-based scientific collaborations that emerge from the NASA-wide water cycle initiative, as well. Planning and coordination efforts will work in tandem with the interagency CCSP, GAPP, and USGCRP elements to advance water-cycle science and prediction.

Task 974-03-070: **(a) Coupling High-Resolution Earth System Models Using Advanced Computational Technologies; (b) A Catchment-Based Global River Routing Scheme for Climate Models and Assimilation of Streamflow and Altimetry Data**

GEST Investigator: Joseph L. Eastman

Collaborators: C. D. Peters-Lidar (Co-I, GSFC), W. K Tao (Co-I, GSFC), P.R. Houser (Co-I, GSFC), Jeffrey P. Walker (Australia), Matthew Rodell (GSFC)

Abstract

Understanding and predicting water, energy, and carbon cycles are of critical importance to such real-world applications as agricultural production, water resource management, and flood, weather, and climate prediction. The primary objective of the work performed under these tasks is to apply advanced computational technologies to the problem of coupling high-resolution (*e.g.,* 1 km, or cloud-scale) Earth system models. Specifically, this work is being done to combine the emerging technologies of the Earth System Modeling Framework (ESMF) and the Land Information System (LIS) to couple complex Earth system model components. The land surface models of the LIS include the Community Land Model (CLM) and the National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force Hydrologic Research Laboratory (NOAH) Land Surface Model (LSM). These state-of-the-art land surface models will be coupled to the Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model to enable high-resolution modeling.

Description of Research

Work to address the potential for coupling high-resolution Earth system models has shown that the development of moist processes is scale dependent. The influences range from the large-scale, synoptic weather systems to microscale phenomena, where land-atmosphere interactions occur. A series of state-of-the-art LSMs are coupled to a cloud-resolving model to investigate the microscale effects on the development of moist processes. Other work entails learning the details of the Weather and Research Forecasting (WRF) model—specifically, the treatment of land surface process. The LIS has also been investigated, and key points of communication between the models have been identified. Both models have been ported to the compiling environment on the GEST investigators PC cluster. The WRF model has been successfully integrated for a preliminary case and analysis proceeds. In addition, modifications for coupling LIS to WRF continue to be implemented. The International H_2O Project (IHOP) data archives have been partially ported to local systems and identification of pertinent case study days completed.

One goal of work on the catchment-based river-routing scheme will be accomplished through the coupling of a River Transport Model (RTM) into the Land Data Assimilation System (LDAS).

Accomplishments during the Reporting Period

The RTM was applied in a case study over the Caribbean Ocean—specifically, the island of Puerto Rico, although calibration issues remain. The RTM algorithm in the Community Land Model (CLM) has also been investigated. This LSM is now part of the LIS model. Several inadequacies in the RTM algorithms have also been identified.

Objectives for the Coming Year

Completion of the coupling of LIS and WRF models will be undertaken. This will entail calibrating and implementing a new surface initialization for WRF. Upon completion, a series of idealized and actual case studies will be evaluated and compared to integrations using default LSMs in WRF, WRF coupled to LIS LSMs, and the Goddard Cumulus Ensemble (GCE) coupled to LIS. Second, a modified Community Land Model RTM will be implemented in LIS and its various submodels. Modifications will include the derivation and introduction of a four-dimensional data assimilation (4DDA) algorithm. Investigation of the application of the RTM at finer mesh sizes will be a priority.

Task 974-03-070: **Global Land Data Assimilation System**

GEST Investigator: Jonathan Gottschalck

Collaborators: Paul Houser (PI, GSFC), M. Rodell (GSFC), U. Jambor (GEST), J. Meng (GEST), K. Arsenault (GEST)

Abstract

The Global Land Data Assimilation System (GLDAS) is a global, high-resolution, offline (*i.e.,* uncoupled from the atmosphere) terrestrial modeling system that incorporates satellite- and ground-based observations to produce optimal fields of land surface states and fluxes in near-real time. The GLDAS framework is mature and is being used to evaluate atmospheric forcings and land-surface datasets, perform sensitivity experiments, incorporate assimilation techniques, and validate land-surface model outputs. The investigator's specific research involves incorporating and evaluating precipitation- and vegetation-related datasets available to GLDAS.

Description of Research

The Earth's land surface exerts a significant impact on the atmospheric boundary layer via fluxes of momentum, energy, and water. As a result, the land surface impacts weather and climate. Current weather and climate forecast models could benefit from improved land surface simulation through initialization of land surface boundary conditions. The uncoupled modeling system used in GLDAS mitigates errors in land

surface storage terms that arise from consistently biased model-based meteorological forcing by making use of satellite- and ground-based observations of radiation and precipitation, thereby constraining land surface simulations and making their outputs closer to observational values.

Accomplishments during the Reporting Period

The investigator's research work has focused mainly on incorporating and evaluating the precipitation datasets available to GLDAS. These include precipitation estimates from model-based systems, satellite-derived retrievals, ground radar, and gauge and merged gauge/satellite products. These precipitation datasets exhibit both advantages and disadvantages depending on geography, meteorological conditions, and season. Consequently, it is important to evaluate under what conditions each dataset performs the best, to determine an optimal configuration.

The datasets included in the analysis included rain gauge estimates from the Climate Prediction Center (CPC); model-based estimates from data assimilation systems, such as that from NASA's Goddard Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS); the National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS); European Centre for Medium Range Weather Forecasting (ECMWF); ground-based radar estimates; satellite-derived products, such as the Tropical Rainfall Measuring Mission (TRMM) real-time Multi-Satellite Precipitation Analysis from GSFC; Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN), from the University of Arizona; and the Climate Prediction Center (CPC) Pentad Merged Analysis of Precipitation (CMAP) rain gauge/satellite product. The CPC gauge data is considered "truth." The evaluation was performed only over the continental United States (CONUS) for March 2002 through February 2003.

Results from this study indicated a broad range of accuracies for the various kinds of precipitation estimates when compared to the CONUS Higgins gauge dataset. There are other important findings from this study. First, the precipitation estimates from the model products generally are more accurate (both in root mean-square error (RMSE) and correlation) than the satellite-derived products, with the ECMWF data showing the greatest accuracy of all the model estimates. A few exceptions to this are evident. During the fall season, the errors for the satellite products are comparable to the model estimates. Also, the correlation of daily precipitation during the summer months for the satellite-derived data is greater than that from the model products, especially across the central U.S. The higher degree of temporal agreement is important because it shows that—although these products overestimate the total rainfall during the period—the timing of intra- and inter-daily areas of precipitation associated with mesoscale convective systems are more accurately represented by the satellite estimates as compared to the modeling products. These findings have implications for GLDAS land surface modeling in that they positively impact the simulation of surface runoff during the warm season, when precipitation often shows greater daily variability over a limited area.

In addition to the offline evaluation of these datasets, yearly GLDAS simulations were performed with four of the precipitation products mentioned above. These included the GEOS model-based precipitation, the GSFC and PERSIANN satellite-only derived precipitation, and the CMAP merged gauge/satellite precipitation product. The GLDAS simulations indicate that land surface states are sensitive to different precipitation forcing. Specifically, total soil wetness, soil temperature, and snow water equivalent, as simulated by the Mosaic land surface model, differ extensively over certain areas of the world. The use of the satellite-only and merged precipitation not only maintains and creates a drier and warmer land surface across much of North America and Southeast Asia, but also develops lower soil wetness and warmer soil temperatures across central and southern Africa, South America, and Australia. The simulation of snowpack water equivalent is comparable for the GEOS, PERSIANN, and CMAP runs, while the GSFC run overestimates its values due to overestimation of precipitation during the winter months—a result of contamination by snow cover. The simulations also demonstrate that soil temperatures are more sensitive to changes in

precipitation forcing for areas where vegetation is relatively low, *i.e.,* where the leaf area index (LAI) is less than three.

Objectives for the Coming Year

In addition to normal maintenance and operational duties for GLDAS, the investigator will extend and complete the precipitation evaluation work. The investigator will continue and complete the assessment of the inclusion of satellite vegetation data into GLDAS and their resulting impacts on land surface simulation. The performance of the Community Land Model (CLM)-1 and -2 land surface models will be evaluated as part of GLDAS, and modifications and improvements will be implemented.

Task 974-03-070: **Global Land Data Assimilation**

GEST Investigator: Urszula Jambor

Collaborators: P. R. Houser (PI, GSFC), M. Rodell (GSFC), J. Meng (GEST), K. Arsenault (GEST), J. Gottschalck (GEST), R. Koster (GSFC)

Abstract

The goal of the Global Land Data Assimilation System (GLDAS) project is to develop a global, high-resolution, near-real-time modeling scheme that makes use of various satellite- and ground-based observation systems within a land-data assimilation framework to produce optimal output fields of land-surface states and fluxes. The GLDAS framework routinely undergoes upgrades and expansion to accommodate forcing data and land surface model options. Practical issues involving the maintenance of operational model simulations, the data archive, and the software were addressed. Interactions with outside communities and researchers continued, including sharing GLDAS output and support and use experience. Off-line experiments were planned and performed to evaluate and attain the objectives of the GLDAS project.

Description of Research

Observation and understanding of atmospheric and land surface processes have been improving steadily over the past two decades, largely due to advances in satellite remote sensing and increased computing capabilities. Relying on atmospheric and land surface models to fill in observational gaps, and incorporating observations into land surface models as forcings and constraints, helps maximize our knowledge of the processes and resulting states of the Earth system. GLDAS will improve land-surface, weather, and climate predictions by providing global fields of land-surface energy and moisture stores for initialization. These global fields will be useful for other applications, including investigations of land-surface management issues and analysis of the relationships between model predictions and observations at various spatial and temporal scales.

Accomplishments during the Reporting Period

The study of the impacts of GLDAS-based land surface initializations on seasonal forecasts continued in collaboration with Global Modeling and Assimilation Office (GMAO) scientists. Building on the work of the previous year, additional 15-year retrospective model runs were performed. Bias-corrected reanalysis European Center for Medium-Range Weather Forecasts (ECMWF) output were merged with observed radiation and precipitation data, and were used as forcing. These data were manipulated to help identify the contributions of each forcing factor on model-generated land surface states. Results from these GLDAS simulations were used to further clarify the results of a study of side-by-side ensembles of seasonal forecasts performed by GMAO researchers. The purpose of this ongoing work is to quantify the impact realistic land surface initial conditions have on such forecasts.

Discussions and plans were initiated between National Centers for Environmental Prediction (NCEP) researchers and the GSFC-based GLDAS team. The GLDAS software is to be ported to the NCEP operational platform and used to initialize versions of the GDAS model. Access to NCEP

computing resources and training was sought. Preliminary tests of the GLDAS software with customized settings pertinent to NCEP conditions were performed and presented. This project will serve as another testbed for GLDAS software, and will facilitate the transfer of advances in land surface modeling and data assimilation back to the operational modeling community.

In addition, the data archives and software associated with GLDAS were tested, maintained, and improved. Daily operational model simulations were performed. In cooperation with Land Information System (LIS) software developers, tests and contrasts of the two software systems (GLDAS and LIS) were evaluated. Significant changes to the data archiving strategy were implemented. Detailed documentation of the new automated archiving system was produced. These computer resource developments all took place while the GLDAS project continued to move toward attaining its scientific research objectives.

Objectives for the Coming Year

As the GEST investigator has retired, there are no objectives for the coming year.

Task 974-03-070: **Land Information Systems**

GEST Investigator: Sujay V. Kumar

Collaborators: Paul Houser (PI, GSFC), Christa Peters-Liddard (GSFC)

Abstract

The research being done under this task involves implementing a Land Data Assimilation System (LDAS) globally at very high spatial resolutions. The proposed Land Information System (LIS) will have a high-resolution Global Land Data Assimilation System (GLDAS), involving several independent community land models and a Web-based user interface that accesses data mining, numerical modeling, and visualization tools.

Description of Research

The Earth's land surface and atmosphere are coupled to each other over a variety of time scales through the exchanges of water, energy, and carbon. An accurate representation of land surface processes is critical for improving models of the boundary layer and land-atmosphere coupling at all spatial and temporal scales and over heterogeneous domains. Long-term descriptions of land use and fluxes also enable accurate assessments of climate characteristics. In addition to the impact on climate modeling, land surface processes also affect the environment for growth of natural vegetation and provision of water resources. The importance of accurate land surface modeling has motivated the development of a land data assimilation system (LDAS) that enables the integration of remotely sensed and model-derived data in a data assimilation framework. The LDAS system has been successful in modeling the land surface processes in both real time and at high resolution for North America. However, to accurately predict land surface initialization and climate prediction, the LDAS system needs to be implemented globally at high resolution and at near-real time. The increased resolution of the global modeling scale of the proposed land information system (LIS) significantly increases the computational requirements. As a result, this problem can be termed a "grand challenge problem."

To understand the scope of the problem requires establishing some boundary conditions: The Earth's global land surface is modeled by dividing it into two-dimensional regions (*e.g.,* cells of size 1 km x 1 km), which results in approximately 5×10^8 million cells. Each cell can have partial spatial coverage by a number of vegetation types, as well as bare soil. The vegetation characteristics such as leaf area index (LAI), stomatal resistance, etc. might be time varying. The conditions in each cell (energy, water fluxes, etc.) are computed at different time intervals. Each cell is driven by different atmospheric forcing variables. Assuming approximately 0.4 milliseconds of computational time for each land surface model run on a particular cell, it can be estimated that modeling land surface processes over a year with 15-minute

time steps would take approximately 74 years. This is the basis for the claim that finding techniques to make this computationally tractable is clearly a grand challenge. In addition to the huge computational requirements, the land surface modeling process must also manipulate large amounts of data. The LIS system will require daily input of approximately 280 gigabytes, and will produce 200 gigabytes of gridded output. Implementation of the LIS system in a parallel environment with a software system that uses a distributed-memory programming model could prove to be a performance bottleneck, since I/O will generate significant network traffic that interferes with scaling the application.

Parallel computing has emerged as the enabling technology to help satisfy such increasing high-performance computing requirements. Such a system is being built, one that takes advantage of scalable parallel computing technologies to facilitate global land surface modeling in a reasonable amount of time. The land surface processes have rather weak horizontal coupling on short temporal and large spatial scales, enabling highly efficient scaling across massively parallel computing platforms. High data densities could pose limitations on land surface modeling efficiencies; the LIS project is exploring the use of high-performance technologies to eliminate this bottleneck.

Accomplishments during the Reporting Period

LIS is one of the Round III Computational Technologies Grand Challenge projects. The project has a number of milestones to be achieved by specified points during the life of the project. The main goal of LIS in the previous year was to develop the ability to perform global, high-resolution, land surface modeling. The ability to perform modeling at 5-km steps globally was demonstrated first, followed by modeling at 1-km global resolution. These achievements required responses to considerable computational challenges; several scalable, high-performance computing technologies were applied to meet these challenges. The system also includes several data management techniques and highly interactive visualization tools for the users.

The high spatial resolution of LIS makes it capable of resolving urban areas, so key ongoing work involves updating land surface models to represent the impacts of engineered surfaces (*e.g.,* buildings, roads, parking lots, etc.) on mesoscale land-atmosphere interactions, including fluxes of water, energy, and momentum. Recent studies have illustrated the dynamics of latent heat flux from a typical ¼ degree resolution run of LIS with the Variable Infiltration Capacity (VIC) model on the southeastern U.S. portion of the global domain. Although certain areas of low evaporation (and therefore low latent heat flux) are evident, the Baltimore-Washington area and the nearby Chesapeake Bay are not immediately evident at this resolution. When the experiment is repeated over the same domain for a global 5-km resolution using the same model, not only is the separation of Baltimore and Washington evident, but also other large- and medium-size urban areas, including Atlanta, Houston, and Richmond, become apparent. At a resolution of 1 km x 1 km resolution for a nested sample subset (*e.g.,* Houston), even more detail becomes apparent.

Another important design goal of LIS was to develop a highly interoperable system. Using object-oriented design principles, a highly modular and extensible framework was developed that can be used by scientists and researchers for rapid application development and to perform scientific studies. LIS currently includes a multitude of land surface models (*e.g.,* the Community Land Model (CLM), National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force/Office of Hydrology (NOAH), VIC, Mosaic, SIB (Simple Biosphere Model), etc). LIS also has the ability to use high-resolution satellite data, such as Moderate Resolution Imaging Spectroradiometer (MODIS)-based products. LIS interoperates with tools provided by other Earth system modeling groups by adopting existing standards, such as the Assistance For Land Modeling Activities (ALMA), and frameworks such as the Earth System Modeling Framework (ESMF).

Objectives for the Coming Year

Research goals for the coming year include specifying a complete interoperable LIS system with tools to interoperate with other Earth system

models. The project also will demonstrate participation with the ESMF as the land-modeling component in an Earth system modeling experiment. Several scientific studies are in progress that examine and validate LIS at high spatial resolutions. Plans call for the studies to validate LIS globally during the Coordinated Earth Observing Period (CEOP). The LIS project will also participate with other land surface modeling activities, such as the Global Soil Wetness Project-2 (GSWP-2), to demonstrate its land surface models and other tools.

Task 974-03-070: **Global Land Data Assimilation System**

GEST Investigator: Jesse Meng

Collaborators: Paul Houser (PI, GSFC), Matt Rodell (GSFC), Jon Gottschalk (GEST), Urszula Jambor (GEST), Kristi Arsenault (GEST)

Abstract

A Global Land Data Assimilation System (GLDAS) has been developed that makes use of various new satellite- and ground-based observation systems within a land surface modeling and data assimilation framework, to produce optimal output fields of land surface states and water and energy fluxes. Initiated in late 2000, GLDAS reached an important milestone at the beginning of 2002. The system has been built successfully, with its hardware and software requirements fulfilled. GLDAS is now running daily in an operational mode. It has many user options to initialize various land surface conditions, to use multiple choices of land surface models, and to be forced by various meteorological model outputs and observations. In 2003 various GLDAS experiments were run by the GLDAS team to test and evaluate the impact of different options, including background atmospheric conditions, initial land conditions, radiation and precipitation forcing, and vegetation dynamics. Results have been presented by GLDAS team members at several conferences.

Description of Research

Land surface temperature and wetness affect—and are affected by—numerous climatological, meteorological, ecological, and geophysical phenomena. Therefore, accurate, high-resolution estimates of terrestrial water and energy storage are valuable for predicting climate change, weather, biological and agricultural productivity, and flooding, and for performing a wide array of studies in the broader biogeosciences. The goal of GLDAS is to develop a system to produce high-quality, high-resolution, global fields of land surface states and water and energy fluxes in near-real time.

Accomplishments during the Reporting Period

The primary task for the past year was to monitor and evaluate the global and regional land surface radiation budget from various products, and to study the impact of radiation on global and regional land surface water and energy cycles. The products evaluated include satellite observation-based product from the Air Force Weather Agency (AFWA), Agricultural Meteorology modeling system (AGRMET), National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS) Geostationary Operational Environmental Satellite (GOES) retrievals, and the global and regional modeling/assimilation-based products from the Global Modeling and Assimilation Office (GMAO) and the National Centers for Climate Predictions (NCEP). The intercomparison between these products and validation against ground observations were made on various spatial and temporal scales. To study the sensitivity of land surface processes to surface radiation, a GLDAS experiment was conducted using altered radiation forcing. Results showed that there surface radiation had significant impact on the processes studied, and that GLDAS is capable of identifying and quantifying those land surface responses.

To enhance NASA/NOAA collaboration on the GLDAS project, a proposal to establish a parallel GLDAS system at NOAA NCEP was submitted

and accepted by the NASA/NOAA Joint Center for Satellite Data Assimilation (JCSDA). This parallel system allows scientists at NCEP to conduct extensive GLDAS experiments and to improve their knowledge of global water and energy cycles at various time scales, ranging from daily to seasonal and annual, thereby contributing to the future development of weather and climate prediction models

Objectives for the Coming Year

Objectives for the coming year are to expand the surface radiation budget evaluation to include all operational global and regional modeling/assimilation products and selected parallel experiments from NCEP and GMAO. Also, the simulated cloud properties from those products will be evaluated. A parallel GLDAS infrastructure will augment the NCEP Central Computing System (CCS) of IBM SP machines, and multiple GLDAS operations for the NCEP Global Forecast System (GFS) land initial condition experiments will be conducted to perform off-line predictions and optimal initial condition studies. An optimal land surface temperature estimation from multiple satellites and sensors will be developed, using ASTER, Terra, Aqua, and geostationary satellites. The results will be tested in various land surface assimilation experiments.

Task 974-03-070: **(a) Optimal Land Initialization for Seasonal Climate Prediction (b) The Effect of Subgrid Variability of Snow Cover in Vegetated Regions on Land-Atmosphere Interactions**

GEST Investigator: Wenge Ni-Meister

Collaborators: Paul Houser (PI, GSFC), Randy Koster (GSFC), Rolf Reichle (GEST), Jeff Walker (Australia), Jiarui Dong (GEST)

Abstract

The one-dimensional ensemble Kalman filter (EnKF) has been developed and implemented in the NASA Seasonal-to-Interannual Prediction Project (NSIPP) catchment-based land surface model (LSM). A major accomplishment was the characterization and evaluation of model error and observational error by comparing the modeled soil moisture and Scanning Multichannel Microwave Radiometer (SMMR) data with *in situ* measurements of soil moisture over a long period over Eurasia. The data assimilation algorithm was also evaluated at the continental scale. How land surface heterogeneity influences boundary layer development in boreal forests, where snow exists for half of the year, was also investigated.

Description of Research

The goal of NSIPP is to improve seasonal-to-interannual climate predictions using global coupled Earth system (*i.e.,* ocean-atmosphere-land-sea-ice) models. Land surface processes contribute significantly to the variance of annual precipitation over continents, while ocean processes have a smaller effect, particularly in midlatitudes. Subsurface moisture and temperature stores exhibit persistence on seasonal-to-interannual time scales; together with external forcing and internal land surface dynamics, this persistence has important implications for extended prediction of climatic and hydrologic extremes. Accurate initialization of land surface moisture and energy stores in fully coupled climate system models is critical for seasonal-to-interannual climatological and hydrological prediction because of their regulation of surface water and energy fluxes between the surface and atmosphere over a variety of time scales. Thus, to improve the initialization of land surface states, a central research activity within NSIPP has been developed to constrain the NSIPP land model with available soil moisture measurements and other land surface variables using a Kalman filter-based data assimilation strategy.

General circulation model (GCM) snow-cover subgrid variability has a significant impact on land-atmosphere interactions due to the high albedo, low thermal conductivity, and melting processes of snow. In highly vegetated mid- and

high-latitude regions, where the presence snow is often found below and between plant canopies, land surface heterogeneity is even more complex; as a result, it is difficult to predict its influence on the atmosphere. A better land surface parameterization scheme to account for subgrid variability in vegetated regions is necessary to study land-atmosphere interactions in regional and global climate and weather prediction models. A hybrid model is being developed to characterize GCM subgrid snow-cover variability in vegetated regions, and to use this hybrid scheme to study the impact of subgrid land surface heterogeneity on land surface processes, surface hydrology, and development of the planetary boundary layer (PBL) during winter and spring. The goal is to develop an improved coupled land-atmosphere model for snow-covered and vegetated regions to study the interrelationships and feedbacks among clouds, precipitation, boundary layer, and land surface processes. The framework includes a hybrid parameterization scheme for the subgrid snow-cover variability in vegetated regions and coupling it with a nonlocal PBL model. The hybrid scheme was developed by incorporating a well-developed canopy radiation model to characterize the variations of radiation regime at forest stand or smaller scales, into a macroscale, process-based land surface model. This hybrid scheme will be coupled with a nonlocal PBL model. This coupled land-atmosphere model is used to study the influences of snow cover heterogeneity in vegetated regions on land surface hydrological processes, the surface energy and water balances, and atmospheric dynamics, such as turbulent boundary layer development, and cloud and precipitation patterns.

Accomplishments during the Reporting Period

The one-dimensional EnKF was developed and implemented in the NSIPP catchment-based land surface model. The error from remotely sensed soil moisture observations from the SMMR and the model was evaluated. The model error and the observation error were characterized and quantified by comparing the modeled soil moisture and SMMR data with *in situ* measurements of soil moisture over a long period over Eurasia. The assimilation algorithm was successfully evaluated using the model error and observation error obtained above.

In other work, the turbulent boundary layer was characterized and quantified using data collected in boreal forests in Central Canada. An algorithm to study the effect of heterogeneous conifer forests on snowmelt in boreal forest was developed and implemented in a land surface processes model.

Objectives for the Coming Year

As this investigator has left GEST, there are no objectives for the coming year.

Task 974-03-070: **Coordinating and Implementing NASA Global Water Cycle Research**

GEST Investigator: C. Adam Schlosser

Collaborators: Paul Houser (PI, GSFC), Deborah Belvedere (GEST), Pierre Morel (retired)

Abstract

This GEST center activity, based at GSFC, supports scientific collaboration and coordination for NASA's global water and energy cycle research. Specifically, planning task forces, consisting of researchers from the broader scientific community and NASA scientists, have been assembled. These task forces have worked to produce and enable implementation plans that not only uphold NASA's Earth Science Enterprise (ESE) strategies, but also answer to the emergence of crosscutting water-cycle research initiatives brought forth by interagency and government/ administrative science panels.

Description of Research

Considerable attention has been given to the importance of the global water cycle in assessing the consequences of natural and human-induced climate change. In particular, the U.S. Global Change Research Program (USGCRP) *Plan for a New Science Initiative on the Global Water Cycle* and the subsequent National Research Council response have identified the global water cycle as

a critical research theme in order to advance climate-change research in the coming decades. More recently, the current administration's Climate Change Science Program (CCSP) has identified the water cycle as a critical crosscutting theme that all science agencies must address in a coordinated and optimally synergistic fashion. As such, the challenge faced by NASA and other government research-agencies is to construct an ambitious, focused, and coordinated implementation plan that will significantly advance our understanding of—and predictive capabilities within—this crosscutting, scientific theme and, generally speaking, climate-change science.

Accomplishments during the Reporting Period

In the past year, a document presenting the scientific foundation and roadmap for a Water and Energy Research (WatER) initiative has been completed. The WatER initiative has been presented to the NASA Earth System Science and Applications Advisory Committee, and is currently under consideration by NASA program managers and ESE administrators. A Web site has been constructed (http://watercycle.gsfc.nasa.gov) to enable efficient dissemination of scientific/planning documents, solicitation of scientific and management inputs (through a Web-based survey), description of NASA water cycle science activities, and correspondence with and education for scientists, educators, students, and the general public.

In conjunction with the scientific planning and coordinating activities, an analysis and synthesis effort was started as an ongoing effort to quantify, balance, and characterize the global vertical fluxes of water (*i.e.*, precipitation and evaporation) using satellite-based retrievals of ocean evaporation, model estimates of continental evaporation (based on standalone land-model simulations forced with observed atmospheric conditions), Global Precipitation Climatology Project (GPCP) precipitation data, and multidecadal simulations from atmospheric general circulation models (AGCMs). Results indicate that our attempts to characterize the general aspects of the global water cycle via satellite retrievals are encouraging, but much more attention is required to accurately quantify and balance the mean states, variability, and trends. In particular, a considerable trend exists in the Special Sensor Microwave/Imager (SSM/I)-based ocean evaporation estimates, which are an order of magnitude higher than the observed precipitation and results from AGCM simulations. Moreover, the interannual variations in the observation-based global precipitation and evaporation estimates are not well correlated in comparison with the AGCM results. The AGCM's interannual variability of the global, annual water fluxes is roughly half that of the observation-based estimates. The observation-based estimates of the relative land contribution (or, conversely, the ocean contribution) to the global, annual evaporation vary from 10-25%. Overall, the observation-based estimates of global, annual evaporation balance precipitation are accurate to within 10%.

Objectives for the Coming Year

As this investigator has left GEST, there are no objectives for the coming year.

Task 974-05-086: **Calibration and Validation of an Algorithm for Retrieving Snowpack Parameters at Global-to-Regional Scales Using NASA's Aqua Satellite Remote Sensing Instruments**

GEST Investigator: Richard E.J. Kelly

Collaborator: Alfred T.C. Chang (PI, GSFC)

Abstract

Snow monitoring from satellite remote sensing is important for effective water resource management, flood hazard prediction, and climate change studies. Routine monitoring of snow global areal extent and water equivalent will improve global climate modelers' simulations and predictions of climate behavior. In addition, resource managers will be able to more effectively manage demands for water supply and avoid hazardous flooding events from melting snow. This research effort is designed to develop, apply, and validate a snow area mapping and snow water equivalent algorithm that will use data from NASA's Aqua satellite, launched in 2002. Snow water equivalent (SWE) has been retrieved from satellite Earth observation instruments for several years, but with data from the Aqua platform spatial resolution and error of snowpack estimation will be improved.

Description of Research

The production of a reliable and well-defined algorithm to monitor snow cover at various time and space scales is of great importance to both the research community (*e.g.,* climate modelers) and the environmental management community (*e.g.,* water resource managers). It is essential to monitor and map snowpack resources within specified ranges of accuracy to better explain (and perhaps improve) predictions of climate change. Global snow cover is an environmental parameter that is highly variable in both space and time. Significant efforts are underway to map daily snow area at local and global scales using the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite. With the successful launch of Aqua in 2002 the potential availability of microwave data from the Advanced Microwave Scanning Radiometer – EOS (AMSR-E) is providing an exciting possibility to map SWE at spatial scales that are half those currently available. Furthermore, the addition of two lower-frequency microwave channels on AMSR-E should greatly improve our ability to successfully map snowpacks in a variety of states (*e.g.,* wet, dry, or layered). The research performed under this task is focused on the development, calibration, and testing of algorithms to effectively map SWE using passive microwave data from AMSR-E.

Accomplishments during the Reporting Period

Task work in 2003 continued to focus on the development and verification of SWE estimation algorithms for AMSR-E image data. Using data from the Special Sensor Microwave/Imager (SSM/I), two approaches were successfully developed as improvements on long-standing methodologies. One algorithm is parameterized spatially, using long-term snow-depth records; the other approach couples a simple hydrological model with a dense media radiative transfer model to produce a spatially and temporally parameterized dynamic algorithm. The lineage of both approaches is predicated on SWE monitoring using passive microwave instruments that date back to the 1980s, when it was observed that dry snow substantially attenuates microwave radiation naturally emitted from the Earth's surface. The strength of this attenuation can be directly related to the SWE of the snowpack. However, the size distribution of ice grains in the pack, the amount of liquid water in the pack, the snowpack stratigraphy, and the geographical location of the snowpack (especially whether or not it is located in a forested area) also control microwave attenuation by snow. In the absence of detailed and widespread information about the physical "state" of a snowpack (*e.g.,* grain size, wetness, surface roughness, etc.), the research effort has combined generic snow "state" factors in an attempt to quantify statistically their spatiotemporal variability.

To test some of these algorithm improvements, the research has also focused on field experimentation, particularly through the large-scale Cold Lands Processes Experiment (CLPE) funded by NASA's Land Surface Hydrology Program. Fieldwork was conducted in February and March of 2002 and 2003. This experiment allowed collection of unprecedented volumes of field snow measurements (*e.g.,* snow depth, density, stratigraphy, etc.), which are helping us to further refine our retrievals of global snow depth and SWE estimation.

Objectives for the Coming Year

Because Version 1 of the SWE product was released in November 2003, the goal of work in the coming year is to further calibrate and validate the AMSR-E snow-monitoring product, especially the snowpack description component. The algorithms are being tested using data from the CLPX (Colorado snowpacks) and from other global sites (*e.g.*. the Ob River in Russia). The product will be tested in collaboration with our Canadian colleagues, using Canadian field data. Furthermore, the CLPX data are being used to provide a benchmark data set against which instrument concepts and configurations for a dedicated snow hydrology measurement program are being developed. This proposed Cold Lands Processes Pathfinder concept is in the planning stages but plans are to propose it in response to the next NASA Earth System Science Pathfinder (ESSP) Announcement of Opportunity (AO).

Task 974-44-183: **Operational Modeling of Soil Moisture at Local and Regional Scales**

GEST Investigator: Yihua Wu

Collaborators: C.D. Peters-Lidard (PI, GSFC), D.R. Webster (GTRC), Feifei Pan (GTRC), P.R. Houser (GSFC), P.E. O'Neill (GSFC), Ann Hsu (GSFC), Mike Tischler (SSAI)

Abstract

Soil moisture is one of the basic links between the water and energy cycles of land surfaces through its regulation of infiltration, runoff, transpiration, and thermal capacity. In this study an operational modeling system of soil moisture at hillslope (local) to watershed (regional) scales has been developed using the community National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force/Office of Hydrology (NOAH) land-surface model (LSM). This system simulates profiles of soil moisture (both liquid and frozen) and soil temperature, skin temperature, snowpack depth, snowpack water equivalent (and, hence, snowpack density), canopy water content, and surface water and energy fluxes, including runoff, infiltration, and evapotranspiration. The system was tested using soil moisture data from the Monsoon '90 experiment, carried out at the Walnut Gulch Experimental Watershed (WGEW), near Tombstone, Arizona. The results show that the system has the potential for operational soil moisture modeling.

Description of Research

Routine or operational estimates of hillslope-to-watershed-scale soil moisture have potential applications in regional resource management, including flood and water resource forecasting, irrigation scheduling, and determining mobility with lightweight vehicles. Hillslope scales may be defined as 10 to 100 m and watershed scales range from 1,000 to 25,000 km^2. Watershed management applications generally require daily soil moisture information to depths ranging from the subsurface (15 cm) to the entire root zone (> 1 m), while remote sensing-based products provide only surface soil moisture at depths ranging from 1-5 cm over biweekly-to-monthly intervals. Therefore, a combined approach is being developed, using Soil Vegetation Atmosphere Transfer (SVAT) models and remotely sensed observations to provide routine daily estimates of profile soil moisture.

SVAT models have generally been developed for weather and climate modeling applications, and typically include solution of a form of the

Richards' equation, including representation of parameters and processes controlling the evolution of soil moisture such as infiltration, evapotranspiration, percolation, and drainage [see also Moran *et al*. 2003]. In this work, a publicly available SVAT model, known as the community NOAH LSM [Chen *et al*. 1996] is applied, which has been validated at point and watershed scales with respect to its water and energy balance predictions. This study has two objectives: to assess the suitability of the SVAT model for operationally predicting hillslope-to-watershed scale soil moisture; and to explore the impacts of land surface and soil hydraulic characteristics on operational modeling of soil moisture at local and regional scales.

Accomplishments during the Reporting Period

Data from the Monsoon '90 large-scale interdisciplinary field experiment were collected and analyzed These data include daily gravimetric soil moisture data (collected at eight micrometeorological-energy flux (Metflux) sites), soil moisture (measured by Time Domain Reflectivity (TDR) sensors at Kendall Lucky Hills), bright temperature data (measured by an airborne L-band Push Broom Microwave Radiometer (PBMR) mounted on a NASA C-130 aircraft), and soil moisture products (derived from measured microwave brightness temperatures on specified days).

The overall error of the PBMR product versus the gravimetric observations collected to a depth of 5 cm has been assessed; the expected compound error is 4.5% $\pm$ 1.9%. The PBMR data is able to capture the dynamic range of the soil moisture observations. Comparison of TDR and gravimetric soil moisture at the depth of 5 cm shows a large difference between the two. However, TDR measurements illustrate reasonable dynamics of soil moisture in root zone.

An operational soil moisture simulation model system for watershed scale was developed based on the NOAH soil hydrology module [Chen *et. al* 1996]. This system is applied to the WGEW for Monsoon '90 by configuring the model to execute over a 660 by 333 grid domain with a horizontal resolution of 40 m. Input parameters and near-surface atmospheric forcing data included precipitation, solar radiation, long-wave radiation, temperature, relative humidity, wind speed and surface pressure, soil texture, and land cover data. The dynamic meteorological forcing data were obtained from Houser [1996], who applied a state-of-the-science interpolation algorithm to precipitation data collected at 88 rain gauges deployed over the watershed. All other meteorological forcings were assumed to be spatially constant, given that they were available only at some of the Metflux sites. Soil texture data sets considered for operational use include, from finest to coarsest resolution, Site Specific Measurement (SSM), Soil Survey Geographic (SSURGO) Soil Dataset, State Soil Geographic (STATSGO) Soil Dataset, and Soil texture from Food and Agricultural Organization of United Nations (FAO) and Scotte *et al.* [2000]. Interestingly, there is only one soil type in the Walnut Gulch watershed in both STATSGO and FAO soil classifications: loamy sand for STATSGO, and Sandy loam for FAO. All soil texture data were mapped to the texture classes of Cosby *et al.* [1984], since NOAH uses their lookup tables to determine soil hydraulic parameters. In addition to the soil texture datasets, saturated hydraulic conductivity and porosity were derived directly from the SSURGO data as an optional input to the LSM. Three land cover data sets were also considered for use in operational soil moisture modeling. They include the 1992 North American Landscape Characterization (NALC) land cover dataset, the Environmental Protection Agency (EPA) and United States Geological Survey (USGS) Geographic Information Retrieval and Analysis System (GIRAS) land cover dataset, and Moderate Resolution Imaging Spectroradiometer (MODIS) land cover. Given that the NOAH model has adopted parameter lookup tables according to the classification of Dorman and Sellers [1989], these land cover datasets were remapped to their 13 land cover types to use the parameter lookup tables within NOAH. In addition, leaf area index (LAI), greenness fraction, and albedo data were obtained from Houser [1996] as optional inputs to the model.

Two experiments were conducted with different objectives. Experiment 1 evaluated NOAH model performance. Five runs were performed. In the

first run, SSURGO soil texture and NALC92 land cover datasets were used along with image inputs of key soil and vegetation parameters. In the other four runs, the K_{sat} values from SSURGO, STATSGO, FAO, and Scotte datasets were multiplied by a factor of 68 or 19, based on the measured K_{sat} at Kendale and Lucky Hills. The modeled soil moisture from the two runs was compared with PBMR for the PBMR area, and with TDR and gravimetric measurements at the Kendall and Lucky Hills Sites. Experiment 2 explored the impacts of land surface and soil hydraulic characteristic inputs on the spatial distribution of model simulations. Three sets of parameter degradation runs were conducted. This first set of runs explored the impact of soil parameter inputs (lookup table vs. images) and the impact of coarser-resolution soil data on operational soil moisture prediction. The second set of degradation runs focused on degrading land cover inputs (tables vs. images) and land cover source datasets from finest to coarsest. The third set of runs explored the impact of degrading precipitation data, by applying averaging windows to the data to simulate rainfall radar inputs and watershed average rainfall. The primary results show the importance of accuracy, spatial resolution, and distribution of dynamic and parameter inputs for the model.

Objectives for the Coming Year

During the coming year the NOAH model will be run using Washita92 experiment data. A mechanistic model for biosphere-atmosphere ammonia exchanges will be developed, and field data will be collected to develop and evaluate a model for biosphere-atmosphere ammonia exchanges.

Task 974-44-184: **Land Information System**

GEST Investigator: Yudong Tian

Collaborators: Paul Houser (PI, GSFC), Christa Peters-Lidard (GSFC)

Abstract

The Land Information System (LIS) has been developed, and improved to the point where real-time global land surface simulations at a resolution of 1 km are now possible. The software and hardware components have been built, and show significantly improved performance, interoperability, portability, and stability. Innovative approaches were devised to overcome the challenges of reliable data replication, efficient and robust job management, dynamic load balancing, and user-friendly data serving.

Description of Research

Land surface models predict terrestrial water, energy, and biogeophysical processes critical for applications in weather and climate prediction, agricultural forecasting, water resources management, hazard mitigation, and mobility assessment. As more and more observational data of the Earth's land surface from remote sensing and direct measurement become readily available (and with increasingly higher resolution), it is necessary to develop a land surface modeling and data assimilation system that can take advantage of the newly available data, providing enough capacity and scalability to handle increasing demands for the foreseeable future. The LIS is an ambitious effort to develop such a leading-edge system. It will support broad land surface research and application activities, take advantage of the increasingly available observational data, and lead effective application of high-performance computing and communication technology to high-resolution, real-time Earth system studies.

Accomplishments during the Reporting Period

Building on developments during the first year's activities, all project milestones set by NASA Earth Science Technology Office (ESTO) Computational Technologies (CT) project were met during the reporting period. These included first code improvement; interoperability prototype from an earlier milestone tested with improved codes; and the delivery of the *FY03 Annual Report* to the Earth and Space Science (ESS) project via the Web.

Critical to attainment of these milestones, was the success of several activities. A stable Linux Beowulf Cluster was operated and maintained. The cluster was designed and constructed during the previous reporting period, and is the central computing powerhouse for the high performance computing and communication. The cluster has undergone several rounds of tuning and renovation to improve its stability and capacity. Second, a customized job management system was developed. Due to the unprecedented scale of computational support needed for high-resolution simulations, none of the currently available job management systems were adequate. Therefore, a custom job management system was built from scratch, with strong features of fault tolerance, automatic load balancing, and friendly and intuitive user interfaces. In theory, with this job management system LIS will scale in a near-linear fashion, which will soon be demonstrated for a forthcoming milestone. Third, an innovative data management system has been developed. Use of LIS brings with it significant demands for data throughput, which resulted in unexpected bottlenecks—challenges that required innovative approaches. The central data-serving system relies on the Gridded Analysis Display System-Distributed Oceanographic Data System (GrADS-DODS) Server (GDS) to provide input data in response to the dynamic requests from the Linux cluster. A GDS server farm was constructed, consisting of five servers, and a load-balancing scheme was implemented to ensure maximum throughput and high availability. This parallel I/O architecture proves to be one of the key factors for the successful operation of LIS at resolutions of 1 km. Fast data replication will further improve LIS' performance. However, the current Network File System-based client-server architecture will soon reach its limit under the high client-to-server ratio observed for LIS. To overcome this limit, current advances in network peer-to-peer (P2P) technology were implemented in the LIS environment. The reliability and scalability of the P2P made timely data replication a reality for LIS, which, in turn, drastically improved LIS' overall performance.

Objectives for the Coming Year

Emphasis for the coming year will be on performance benchmarking, further interoperability implementation, and customer delivery. The goal is to operate LIS in operations-like mode, and to begin serving LIS products to the land research community. In addition, as the user base widens, assistance will be provided and further development will port LIS to other operational centers, such as the National Centers for Environmental Prediction (NCEP). Moreover, many challenging issues have arisen during LIS development in the areas of parallel I/O, network traffic dynamics, etc., which deserve further research and investigation to help ensure continued scalability and utility for the system.

Task 974-52-197: **(a) Global Validation of EOS-Aqua Land Surface Dynamics using Data Assimilation (b) HYDROS Risk Reduction Research Activities**

GEST Investigator: Xiwu Zhan

Collaborator: Paul Houser (PI, GSFC)

Abstract

Several advances have been made through work on the Aqua Land Product Validation and Hydrosphere State Mission (HYDROS) projects. Work included participation in an international field experiment on soil moisture observations in Chickasha, Okalahoma, called SMEX03, and an international field experiment on soil moisture observations in Simpson Desert, in South Australia. The GEST investigator was part of the organizing committee of the Ecosystems' Dynamics, Agricultural Remote Sensing and Modeling, and Site-Specific Agriculture meeting for SPIE's 48th Annual Meeting. Several approaches for soil moisture retrievals from HYDROS radar and radiometer observations have been developed using Kalman Filter data assimilation methodologies.

Description of Research

The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) soil moisture product validation project has been organized to determine the nature and variability of uncertainties in selected global soil moisture and snow products obtained with the EOS-Aqua AMSR-E sensor on a variety of time scales, and to analyze the effects of these uncertainties on the predictability of the global surface water and energy balance using land surface data assimilation techniques in near-real time. Specifically, innovative land surface data assimilation techniques are being used to check the quality control, physical consistency, and systematic realism of global EOS-Aqua land observations, in the context of the collaborative, real-time Land Data Assimilation System (LDAS) project.

The HYDROS risk reduction research activities include developing the HYDROS Observing System Simulation Experiment data set and soil moisture retrieval algorithm for a quantitative assessment of the accuracies of the algorithms.

Accomplishments during the Reporting Period

For the AMSR-E soil moisture validation project, the land surface data assimilation system is equipped with the Extended Kalman Filter (EKF) data assimilation algorithm to uptake soil moisture satellite observations. This procedure will be used to validate the AMSR-E soil moisture data product, scheduled for availability in March 2004. Two large-scale field experiments (one in Chickasha, OK, and another in central Australia) were conducted to collect *in situ* observations to validate the AMSR-E data product.

Several Kalman filter algorithms have been tested for retrieving soil moisture from HYDROS radar and radiometer observations. Results, presented to the HYDROS science team, have shown their advantages over traditional soil moisture retrieval algorithms.

Objectives for the Coming Year

The main focus for the coming year will be to develop a near-real-time operational land data assimilation system that will monitor spatiotemporal AMSR-E soil moisture and snow observation product quality to provide feedback about observational problems to mission operators. This system will also extend AMSR-E products in time and space to produce consistent data assimilation land surface fields that will be valuable for use in subsequent analyses and applications. Finally, selected *in situ* and airborne land surface observations will be used as a secondary test of data integrity. The proposed innovative validation strategies will be used to provide feedback to improve calibration and accuracy of EOS land-surface observations. These improvements will lead to enhanced characterization of the spatial and temporal dynamics of uncertainties in these critical land surface quantities, and will benefit climate and weather prediction efforts. For the HYDROS project, participation will continue in science team research activities.

Task 974-52-198: **Quantify the Errors in Passive Microwave Snow Water Equivalent Estimates, and Assimilate the Remotely Sensed Snow Products into the NASA NSIPP Land Surface Model**

GEST Investigator: Jiarui Dong

Collaborators: Paul R. Houser (PI, GSFC), Jeffrey P. Walker (Australia), James L. Foster (GSFC), Randal D. Koster (GSFC), Chaojiao Sun (GEST), Wenge Ni-Meister (Hunter College)

Abstract

Research over the reporting period focused on quantifying the errors in retrieving the Scanning Multichannel Microwave Radiometer (SMMR) snow water equivalent (SWE) products (from 1979 to 1987) from various land surface data sources: water bodies, forest density, elevation, surface roughness, and temperature. The global

vegetation water content (VWC) products from both Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data were generated.

Description of Research

The research performed under this task on SWE and VWC supports several projects: One is the assimilation of remotely sensed SWE observations over North America in the catchment-based land surface model. This research focuses on quantifying the error statistics of passive microwave snow data from satellites, and assimilating the satellite products into the NASA Seasonal-to-Interannual Prediction Project (NSIPP) land surface model to generate global SWE products. Other work supports NASA's HYDROS mission, which will provide the first global views of Earth's changing soil moisture and land surface freeze/thaw conditions, leading to breakthroughs in weather and climate prediction and in the understanding of processes linking the water, energy, and carbon cycles. The research performed by the GEST investigator on estimating VWC will help to define an important water store that must be accounted for when estimating soil moisture and frozen ground. The third project addressed under this task calls for assisting in the development of an optimal land initialization for seasonal climate predictions. The primary objective of this work is to explore the optimal initialization of the land system in NSIPP models, using relevant remotely sensed observations within a land data assimilation framework. The last major area of support is for the Global Land Data Assimilation Scheme (GLDAS), the goal of which is to produce optimal global fields of land surface status and fluxes.

Accomplishments during the Reporting Period

The U.S. Global Change Research Program (USGCRP) selected the GEST investigator's research on remote sensing estimates of northern forest carbon as a *FY02 Recent Accomplishment* in April 2003. Further into the reporting period, the GEST investigator generated a 20-year monthly, global, 1-km leaf area index (LAI) data set as a dynamic vegetation forcing for the GLDAS and the NSIPP land surface model. This product was derived from AVHRR 8km normalized difference vegetation index (NDVI) data and the University of Maryland's 1-km land cover map. A global high-resolution (1km) vegetation water content (VWC) data set was developed from AVHRR and MODIS LAI, with temporal coverage from 1982 to 2003 at a biweekly interval. This research will provide a global of view how satellite sensors detect the soil water content. These studies all serve to improve our understanding of how the various components of the hydrological cycle interact, provide important information about the current structure of global hydrology, and help describe how humans are changing the global hydrological environment.

Snow plays an important role in governing the Earth's global energy and water budgets due to its high albedo, low thermal conductivity, and considerable spatial and temporal variability. The goal of research under this task is to quantify the uncertainty in passive microwave snow water equivalent retrievals and to generate accurate initialization of seasonal-to-interannual predictions in the NSIPP fully coupled general climate model. Several problems were found in the passive microwave retrievals of snow from the SMMR. First, SMMR snow estimates show significant fluctuations during winter over wide areas. These fluctuations are reasonable for satellite products, because the algorithm used in retrievals is simple and many snow processes are not accounted for. However, these problems need to be further corrected, especially when SMMR data are to be assimilated into land surface models. One cause of the fluctuations may be the changes in footprints due to orbital drift. A second cause may be cloud cover, which warms the surface temperature at night. Another problem with SMMR retrievals is that sharp changes of snow water equivalent can take place from one day to the next. For example, SWE has been observed to drop from a large value to zero, and then change back to a large value almost immediately, usually in the early spring. Warm temperatures melt the snow during the day, and the liquid water increases the emissions in the 36 GHz band.

A third problem addressed under this task is the effect of open water bodies on snow retrievals. Large water bodies, such as oceans and large inland lakes, will result in snow-free signals for

the SMMR retrieval algorithm; this effect must be addressed. Another problem results from the physical properties of snow. For warm regions with temperatures above freezing during the daytime, snow melting makes snow wet and changes snow crystal size, which in turn significantly influences snow's emission characteristics. In very cold regions snow crystals increase in size and over time. Treating snow crystal as a constant, as they are in current retrieval algorithms, thus causes estimation errors.

To investigate some of these issues further, comparisons were made between SMMR estimates of SWE and ground measurements from snow gauge sites in North America. To match these *in situ* data with remotely sensed satellite data, observed SWE values were averaged over each SMMR pixel at a quarter-degree resolution. Regression equations were derived to statistically explain the impacts of water on the satellite signals in retrieving SWE and the impacts of air temperature on snow physical properties from the statistical analysis of field SWE estimates, station positions, and air temperature.

Objectives for the Coming Year

Based on the regression equation described above, the errors in passive microwave SWE retrievals were predicted, and it was found that the errors vary over time and space. These error maps, together with satellite products, will be used as input to data assimilation systems to generate more accurate snow products.

Task 974-52-199: **The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and Forecasting for Water Resources Management in the Columbia River Basin**

GEST Investigator: Kristi Arsenault

Collaborators: Paul Houser (PI, GSFC), David Matthews (U.S. Bureau of Reclamation), Steffen Meyer (U.S. Bureau of Reclamation)

Abstract

The Global Land Data Assimilation Systems (GLDAS) team has used the latest Land Information Systems (LIS) code to enhance simulations and to improve model simulation efficiency. The inclusion, testing, and parallelization of the National Centers for Environmental Prediction (NCEP)/Oregon State University/Air Force/Office of Hydrology (NOAH) Land Surface Model (LSM) are now complete. Components of the modeling framework of the GLDAS and LIS projects are now being adapted for use with applications projects. Retrospective investigations of the North American Monsoon's effects on land surface predictability has led to a three-year continuation of the work, the focus of which has expanded to include Mexico and to use the NASA atmospheric general circulation model (AGCM), the finite-volume Data Assimilation System (fvDAS), remote sensing products from Moderate Resolution Imaging Spectroradiometers (MODIS), and other LSM products from GLDAS and LIS. New projects have begun in collaboration with several agencies, including the U.S. Bureau of Reclamation (USBR) and the Environmental Protection Agency (EPA). Two major projects with the USBR include flood forecasting for the Columbia River Basin and improved estimation of evapotranspiration from the Middle Rio Grande River in New Mexico.

Description of Research

Much of the work developed from the **G**LDAS and LIS projects is now being adapted for applications work to build upon existing relationships with agency partners, like USBR and EPA. The 1-km-resolution domain LIS framework is being used as a baseline from which to design more customized, high-resolution modeling framework solutions for specific geographical regions. For each region, different national weather forecasting model outputs are being evaluated to determine how they perform as inputs to flood prediction models that are used in day-to-day irrigation planning. The NCEP National

Regional Reanalysis product is also under investigation; it may become a major part of retrospective and long-term modeling and statistical studies. Satellite observation products are being integrated into this research; these include those from Landsat, the MODIS instrument aboard the Earth Observing System (EOS)'s Terra and Aqua platforms, and the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) platforms. Other products will be similarly assessed. Research on the North American Monsoon system focused on the effects of varying land cover/land classes and terrain on surface energy fluxes during antecedent summer and peak-summer monsoon activity. The effects of topography strongly control the distribution of rainfall and hence the surface energy heat budget. This in turn can play a role as a feedback processes to the atmosphere. The potential effects of the land cover/land class change on local monsoon events is much less than the effects from different land surface variables that were identified in previous studies for the Southwestern U.S. Active vegetative processes in Mexico may play a significant role in summer monsoon activity. A continuation of the original study is planned to investigate the effects of other surface conditions (*e.g.,* sea surface temperature and snow cover) in a coupled atmosphere-land model framework.

Accomplishments during the Reporting Period

Applications research collaborations have been established with several government agencies, including the USBR, the EPA, and the U.S. Department of Agriculture (USDA). These collaborative efforts involve applying NASA remotely sensed products and modeling system components (*e.g.,* from GLDAS and LIS) to decision support systems (DSS) that are being developed and used for water resource management. Several meetings took place with these agencies to draft and sign Memoranda of Understanding (MOUs), which allow the agencies to share information and to enhance their ability to work together. Two collaborations with the USBR were funded to begin work in two major river basins, each focusing on slightly different issues pertaining to water management. Further collaborative projects were also outlined and established with the EPA, and are now underway. To help in this research, the water management applications team has expanded to include three new personnel.

The GLDAS project continues based on the success of the first stage of the research plan. The GLDAS and LIS projects have benefited from collaborative interaction between the two teams. The GLDAS team now uses the modified (and highly efficient) LIS code to run faster simulations and is reincorporating many research aspects unique to GLDAS back into the system. The NOAH LSM was fully incorporated and parallelized into the LIS project.

A grant awarded this past year includes a three-year continuation on the work on retrospective investigations of the North American Monsoon's effects on land surface predictability. This project has an expanded focus to include Mexico, the use of the NASA AGCM, the fvDAS, and MODIS land products assimilated into a LSM.

Objectives for the Coming Year

Validation and modeling studies will be performed for the Columbia River and Rio Grande River basins. North American Land Data Assimilation System (NLDAS) forcing and output and *in situ* data will be used by the USBR to provide a benchmark for future work. Projects with the U.S. Geological Survey (USGS) and EPA will continue. The 1 km x 1 km resolution domain of the LIS is being used as a baseline to develop a more customized modeling environment for each region and associated water-related issues of interest to partnering agencies. Evaluations of different forecast data sets, river runoff schemes, and certain key satellite observation-based products, such as MODIS-derived snow cover and vegetation classes, will be assembled at high spatial resolution in each region. Further development of key parameters in the LDAS projects will involve specified MODIS land products to be assimilated and tested in the NOAH LSM. The North American Monsoon system research will include further quantification and statistical analyses of the different land surface parameters and variables in terms of their responses and influences on the overlying atmosphere. A major validation study will be

undertaken to evaluate different precipitation products over Mexico and the impacts on the land surface predictability. Experiments will be conducted with the AGCM and remote sensing products from MODIS, and ingested into a LSM known as the Community Land Model, version 2.1.

Task 974-52-199: **Water Resources Management Research Coordination**

GEST Investigator: Jonathan M. Triggs

Collaborators: Paul Houser (PI, GSFC), D. Toll (GSFC), J. Entin (GSFC/HQ), K. Arsenault (GEST), A. Pinheiro (NRC), T. Engman (GSFC [retired])

Abstract

NASA's National Applications Program has identified several research goals that are beginning to be explored. Partner agency decision support systems (DSSs) are being evaluated for potential improvements using NASA data products. Collaborations with water researchers are being established to enable this research.

Description of Research

Many agencies rely on decision support tools for efficient water management and decision-making. The primary goal of this research is to help improve partnering agencies' DSSs using data that are unique to NASA. These include the Environmental Protection Agency (EPA)'s Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), the U.S. Bureau of Reclamation (USBR)'s Agricultural Water Resources Decision Support (AWARDS) system, and Riverware, a tool utilized by USBR and other partner agencies. As the tools are evaluated, potential areas of improvement will be identified. NASA satellite and model output, such as from the Land Information System (LIS) project, the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Shuttle Radar Topography Mission (SRTM) may be able to enhance partners' decision support capabilities. The feasibility of using NASA data to improve such DSSs continues to be explored. After evaluation and testing, validation and benchmarking will need to be completed, and final reports issued on the improvements enabled by NASA products.

Accomplishments during the Reporting Period

Research collaborations were established and developed with NASA's partner agencies to properly evaluate and assess their needs. By the end of the period, many connections were made with water researchers at the USBR and EPA. As part of the research coordination, many new products and programs were made known. NASA data products and modeling systems were carefully assessed in addition to outside decision support tools such as BASINS and AWARDS. There was significant input into the types of research and evaluations to be made, based on several interagency meetings, leading to commencement of evaluation activities for BASINS. A study area focusing on northern Georgia has been established, and testing of MODIS products (such as vegetation and land cover) has begun. To effectively test, validate, and benchmark DSSs such as BASINS, the applications team recently began implementation of geographic information systems (GIS) technology, and work to bring NASA satellite and modeling products into a GIS environment has begun.

Objectives for the Coming Year

In the coming year, evaluations of BASINS will continue, along with support for AWARDS DSS testing. Incorporating certain NASA products will be assessed with the partner agencies to see if this will improve their decision support system capabilities. The first focus will be on BASINS, which incorporates both the Soil and Water Assessment Tool (SWAT) and the Hydrological Simulation Program – Fortran (HSPF) models. Both models will be assessed, and NASA data will be incorporated and tested. Similar procedures will be applied to Riverware and AWARDS.

Global Energy and Water Cycle Experiment (GEWEX)

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Task CV526590: **International Global Energy and Water Cycle Experiment Project Office**

GEST Investigator: Richard Lawford

Collaborators: Robert Schiffer (PI, UMBC), Paul Try (STC), Soroosh Sorooshian (University of California, Irvine), John Roads (Scripps), Bill Rossow (GISS), Jan Polcher (Laboratoire de Météorologie Dynamique du CNRS, Paris, France), Gilles Sommeria (WCRP, Geneva)

Abstract

The Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP) brings together a significant component of the world climate community in joint initiatives to advance our understanding of coupled hydrologic and atmospheric processes on a global scale. Among other activities during the reporting period, significant effort has gone into communicating details of GEWEX efforts to international audiences at all levels; organizational improvements have been developed and promulgated; and the Integrated Global Observing Strategy (IGOS) Water Cycle theme was developed and accepted.

Description of Research

The research undertaken within the Global Energy and Water Cycle Experiment (GEWEX) is directed at developing and applying planetary Earth science and observations to the problems of climate and water resources. Scientists from over 28 countries participate in large projects to determine water and energy fluxes by global measurements of observable atmospheric and surface properties; to model the global hydrologic cycle and its effects on the atmosphere, oceans, and land surfaces; to develop the ability to predict the variations of global and regional hydrologic processes and water resources, and their response to environmental change; and to foster the development of observing techniques, data management, and assimilation systems. GEWEX activities deal with land-atmosphere coupling processes and models, cloud system modeling, global data set development, and water resource applications. In particular, efforts are directed at producing consistent descriptions of the Earth's energy budget and water cycle and their variability and trends, and data sets for developing and validating climate and hydrologic models.

The GEST investigator's role is to direct the office that coordinates this research, synthesizes the results, and establishes processes for making them useful for different communities. The information and synthesis roles are aided by a Web site (http://www.gewex.org), scientific meetings, and the preparation of review articles for different publications. Promotion of the program is done through a newsletter and participation on committees involving the development of observational systems. Within the framework provided by the program, the GEST investigator applies his expertise to gaining a better understanding of national and international water resources issues and to developing better observational systems (especially space-based) that could support the scientific goals of GEWEX.

Accomplishments during the Reporting Period

During the reporting period, the GEST investigator was appointed Director of the International GEWEX Project Office (IGPO), which is responsible for coordinating the activities of the GEWEX project. He has coordinated the preparations for the GEWEX Scientific Steering Group meeting in Morocco, both in terms of providing briefings and written material, and in developing strategies to implement recommendations from the meeting. Through collaborations with the WCRP, he has been successful in negotiating the terms for a European GEWEX coordinator, who will report to him starting in summer 2004. He has also been active in establishing the programmatic structure and putting resources and people in place for the Fifth International GEWEX Conference to be held in Orange County, California in 2005.

Other work has involved related satellite activities, since the GEST investigator serves as the WCRP representative on the executive of the IGOS-

Partnership (IGOS-P) water cycle theme. This theme was accepted by IGOS-P in October 2003, and work is progressing towards the development of an implementation plan.

During the reporting period, the investigator has given a number of presentations on the GEWEX program at international and national conferences. Some of these reviews have been consolidated into journal articles, including one that chronicles the development of hydrometeorological activities within the GEWEX program [Lawford *et al.*, 2004a].

The GEST investigator has overseen production and distribution of regular quarterly newsletters to as many as 2100 recipients per issue, overseen the upgrade of the GEWEX Web page (http://www.gewex/org), and continued to develop a brochure on the accomplishments of the program. In addition, several documents have been reviewed to provide GEWEX views on issues such as the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) program of International Geosphere-Biosphere Program (IGBP). The investigator has also supported the chair of the SSG and the chairs of GEWEX panels by assisting in the preparation of meeting minutes and negotiating action items arising from meetings.

During the past year, on behalf of the WCRP, the investigator has cochaired the writing team for the Integrated Global Observing Strategy Water Cycle theme. Since October 2003, work has continued to finalize the water cycle theme report for distribution to the Group on Earth Observations (GEO) that has been formed as a result of the Earth Observing Summit.

The investigator also served as lead editor for a book entitled, “Water: Science, Management, and Policy”; the book was published by the AGU in December 2003. This multi-authored book provides an overview of many of the scientific, social, and political issues associated with the management of water, with a particular focus on the United States. The investigator has also promoted the development of indicators to enhance the dialogue between scientists and policy makers. His paper on GEWEX, indicators, and integrated water management was presented to a conference on monitoring water in the Netherlands, and has been approved for inclusion as a chapter in a book [Lawford *et al.* 2004b].

Objectives for the Coming Year

During the coming year, links between GEWEX and the outside science and assessment communities (*e.g.,* the Intergovernmental Panel on Climate Change; IPCC) will be strengthened through workshops and reviews; support for the GEWEX program will be provided by preparing minutes of meetings, organizing meetings and conferences, maintaining a Web page, and maintaining a newsletter and occasional publications; developing and supporting the IGOS-P implementation for the water cycle theme by representing WCRP on the theme executive board and leading the implementation of the theme; and providing assistance for the review of various GEWEX elements, including the International Satellite Land Surface Climatology Project (ISLSCP), the GEWEX hydrometeorology panel, and other activities.

Goddard Visiting Fellows Program in the Earth Sciences

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Goddard Visiting Fellows Program in the Earth Sciences

The Goddard Earth Sciences and Technology Center (GEST) and the GSFC Earth Sciences Directorate solicited qualified doctoral-level scientists for collaboration in scientific research relating to the observation, analysis, and modeling of physical processes within the Earth-atmosphere system, and to relevant global change issues. Selected candidates were appointed as visiting fellows to pursue independent research in collaboration with scientists in the laboratories within the Earth Sciences Directorate. They have full access to NASA computing facilities and other resources at either GSFC or the Goddard Institute for Space Studies (GISS) in New York, NY. This solicitation addressed post-doctoral to senior scientists, and emphasized university faculty interested in sabbatical arrangements.

Research interests in the Earth Sciences Directorate include attaining knowledge and understanding of the components of the Earth system through experimental and theoretical studies using NASA technology, information science, and space observations. The approach includes instrument, algorithm, and model development, involving remote sensing and *in situ* measurements. The principal components of research and corresponding research interests are as follows:

Atmospheric Research involves the structural, dynamic, radiative, and chemical properties of the Earth's troposphere, stratosphere, mesosphere, and thermosphere, and the atmospheres of other planets. Research interests include ozone, clouds, aerosols, precipitation, regional and global climate, fronts, gravity waves, cyclones, thunderstorms, and convective systems. Data are derived from various space-based and airborne optical, UV, and IR passive radiometers and laser sensors, and *in situ* spectrometers.

Terrestrial Physics Research involves geological and geophysical processes of the solid Earth and the planets, and global land surface properties, both vegetative and biological. Research interests include Earth and planetary gravity and magnetic fields, Earth's rotation, plate motion, volcanic activity, post-glacial rebound, land surface topography, biospheric processes, vegetation monitoring, and biosphere-atmosphere interactions. Data are derived from space- and ground-based lasers, laser altimeters, and field campaigns involving measurements in local ecosystems and the climate/oceanic/biospheric system.

Hydrospheric Research involves the oceanic, cryospheric, and hydrologic sciences. Research interests include the natural variability of the physical climate system on seasonal-to-interannual time scales, the global carbon cycle, global land ice and sea ice cover, the global hydrological and energy cycles, and interactions between the physical climate system and biogeochemical cycles. Data are derived from optical, microwave, and laser sensors, and *in situ* hydrologic measurements.

Information Science and Technology Research involves computer science, computer engineering, computational science, and information science research in support of NASA Earth system science. Research interests include numerical algorithms and high performance/parallel computing; data assimilation and data fusion; adaptive, multi-resolution modeling; 3-D visualization, feature recognition and multi-dimensional data visualization; and data mining and data management of extremely large distributed data sets. Data are derived from various space-based and airborne sensors, field campaigns, and models.

Appointments are normally for periods up to one year, with terms and negotiable start dates. Visiting Faculty appointments are made at UMBC. Applications are reviewed and selections normally made by April each year. Under special circumstances, appointments can be made at other times of the year. Review is conducted by a panel of university and NASA scientists, based on relevance to NASA's missions, expertise and credentials offered, and clarity and feasibility of stated research goals within the

proposed time frame and available resources. Compensation is commensurate with experience and qualifications.

Goddard Visiting Fellows selected in 2002 (and included in this reporting period) were:

Dr. Kathy Whaler
University of Edinburgh
United Kingdom

Dr. Jacques Hinderer
Institut de Physique du Globe
Strasbourg, France

Goddard Visiting Fellows selected in 2003 were:

Dr. Warren B. Cohen
U.S. Department of Agriculture Forest Service
Pacific Northwest Research Station
Corvallis, OR

Dr. Carlos Alberto Eiras Garcia
Department of Physics
Federal University of Rio Grande
Brazil

Dr. Virginia Maria Tavano Garcia
Department of Oceanography
Federal University of Rio Grande
Brazil

Dr. Fiedemann Freund (tenure to begin in May 2004)
Department of Physics
San Jose State University
San Jose, CA

Dr. Maeng-Ki Kim
Dept. of Atmospheric Science
Kongju National University
Republic of Korea

Professor Roger H. Lang
Department of Electrical & Computer Engineering
George Washington University
Washington, DC

Dr. Robert Numrich
Supercomputing Institute
University of Minnesota
Minneapolis, MN

Postdoctoral fellows selected in 2003 were Dr. Susanne Bauer and Dr. Hyung Rae Kim

Robert Schiffer, Chief Scientist

Task 900-37-172: **Modeling Heterogeneous Chemistry**

Goddard Visiting Fellow Susanne E. Bauer (GISS)

Collaborators: Dorothy Koch (GISS), Drew Shindell (GISS), Jan Perlwitz (GISS), Ron Miller (GISS)

Abstract

Heterogeneous chemical reactions (reactions on surfaces) and multiphase chemistry (reactions of gas-phase species taking place in the liquid phase) are important processes that impact the atmospheric sulfur cycle. Sulfate aerosols have a significant effect on the atmospheric radiation budget, and therefore need to be included with other radiative active aerosols in climate experiments. The amount of sulfate simulated in a climate model depends on its sources, sinks, and chemical transformations. In addition to the uncertainties associated with these single contributions, there is a tendency for sulfate models to overestimate SO_2 concentrations. These discrepancies may be caused by a lack of heterogeneous reactions. Heterogeneous reaction pathways are highly uncertain, which is reflected by the wide spread of reaction pathways and uptake probability coefficients found in the literature. The model under study here focuses on the impact of reactive mineral dust and sea salt surfaces on sulfate formation. First results show that these heterogeneous reaction pathways provide a significant loss mechanism for SO_2 concentration, whereby the total amount of sulfur formation is increased due to additional sulfur production on nonsulfate aerosol surfaces. The sulfate coating on mineral dust aerosols leads to changes in aerosol properties, which in turn can impact deposition rates and effect aerosol radiative properties.

Description of Research

The Goddard Institute for Space Studies (GISS) model is a state-of-the-art global general circulation model that predicts sulfate, sea salt, mineral dust, and carbonaceous aerosols. Heterogeneous interaction between SO_2, mineral dust, and sea salt aerosols are included in the climate model. Different uptake mechanisms, including a range of uptake coefficients, are tested in the model.

First, the general impact of heterogeneous reactions on the global sulfur cycle is analyzed by comparing two simulations: A control simulation (called hereafter CTR) where no interactions between SO_2 and mineral dust or sea salt aerosols are considered, and a simulation (HET) where heterogeneous uptake processes are included. SO_2 is oxidized by O_3 to form a stable sulfate on the aerosol surface. The chosen uptake rates are within the range of the observed coefficients. No alkalinity, humidity, or surface saturation effects are included in the present simulation. When comparing the HET to the CTR simulation, a substantial loss of SO_2 concentrations—56% of the total mass—is simulated in the Northern Hemisphere. This significant loss in SO_2 leads to a reduced production of pure sulfate aerosols, but to additional sulfur production on the aerosol surfaces. Most of the sulfur aerosols are attached to the smallest mineral aerosol particles. The smallest mineral aerosols, ranging from 0.1 to 1 μm in our model, are distributed widely throughout the Northern Hemisphere.

The overall reduction of pure sulfate aerosols is about 45% of sulfate mass between the two experiments, but the additional heterogeneous sulfate production increases the total sulfate mass by about 40% in the HET simulation as compared to CTR. Heterogeneous reactions between SO_2 and sea salt particles show their strongest impact on European SO_2 concentrations, where polluted and marine air masses get mixed. Additional sulfur formation on the sea salt particles seems to be negligible because of the fast removal processes and, therefore, the short lifetime of sea salt particles.

Due to surface coating of sulfate on dust aerosols, the solubility of the particle is changed. As a first approach, a dust particle is assumed to be soluble

when coated by sulfate. This assumption leads to increased washout of dust particles close to their source regions. This increased removal process leads to a 28% decrease of mineral dust mass in this first simulation.

The following aerosols are coupled to the radiation in the climate model: sulfates, black and organic carbon, mineral dust, and sea salt. Sulfates scatter incoming solar radiation, leading to a cooling effect at the Earth surface. In the HET simulation, pure sulfate aerosols are reduced, leading to a reduction of the short wave radiative forcing by sulfate aerosols from -0.56 W/m^2 to -0.33 W/m^2. This is caused by the reduction of the pure, radiation scattering, sulfate aerosols, and production of sulfate on dust particles, which are still assumed to absorb and scatter radiation as dust particles, due to the much bigger size of dust particles. The reduced dust load has only a very small impact on the radiative forcing.

Accomplishments during the Reporting Period

The first year was mainly consumed by model development. GISS is developing a new version of the GISS climate model. The GEST visiting fellow implemented a nudging facility in the GISS model, so that the model can be driven by reanalysis winds. This is very important for future work, because of the desire to simulate several measurement campaigns with the model. Other work addressed aerosol and chemistry routines and developing new routines to include heterogeneous processes in the model. Together with Dorothy Koch, the GEST visiting fellow is taking part in the Aerosol Model Intercomparison Project (AEROCOM), a model/observation comparison program.

Objectives for the Coming Year

The main focus of the latter part of the year will be to apply the new developed heterogeneous chemistry routines in the GISS model, and to simulate measurement campaigns. The focus will be on simulating campaigns where the chemical composition and radiative properties of aerosol have been observed. New routines will be validated with these comparisons, so that climate runs can be performed to study the impact on climate of the studied heterogeneous reactions.

Task 900-37-172: **Forest Characterization and Inventory**

Goddard Visiting Fellow: Warren B. Cohen

Collaborators: Jeff Masek (GSFC), Forrest Hall (GSFC), Sam Goward (UMCP)

Abstract

There are three components to this research effort. The first is to begin research with colleagues at GSFC to characterize forest disturbance across North America using Landsat data. The second objective is to continue research associated with more-detailed disturbance characterization using Landsat data across three intensive study areas in the Mid-Atlantic region. The third is to work toward better integration of the U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program and its data into the North American Carbon Program (NACP). Incremental progress has been made on all three components.

Description of Research

An important part of the NACP program is accurate characterization of forest disturbance regimes across North America. Both projects under this task support these program objectives. The more general characterization across North America is a first step at understanding how North American forests have been disturbed, in relatively coarse time steps of 10-15 years. The Mid-Atlantic project is focused on short time steps of 1-2 years. Together, these projects are helping us understand what the general disturbance regimes are and what errors are associated with an increment of 10-15 years for characterization of that disturbance. To effectively use remote sensing data, ground reference data are required. FIA data are the most

extensive and consistent data available for this purpose in the U.S. However, these data can only be used effectively if the spatial locations of the plots from which they come are known—at least, to a first approximation. Given the plot confidentiality requirements for FIA, plot location information can only be known to users of the data under very specific arrangements. The investigator is working with the FIA program to help establish a suitable arrangement for the NACP.

Accomplishments during the Reporting Period

Working with Masek and Hall and their extended team, the investigator and his collaborators have worked through some basic problems in radiometric processing of the historic Landsat Geocover datasets (*e.g.,* 1975, 1990, and 2000). Radiometric calibration is a key preprocessing step that must be done effectively for the data to be used for disturbance characterizations. Bulk processing of large data volumes presents unique problems for achieving radiometric calibration. Using a variety of ancillary datasets, specific problems with Landsat calibration have been identified and are currently being evaluated. Discussions have begun about the prospect of using the calibrated Landsat data for disturbance characterizations. The aim is to provide an automated disturbance characterization system; however, finding the proper balance between deterministic and empirical models is a challenge.

With Goward and Masek, the GEST investigator has begun the analysis of biennial spectral changes associated with forest disturbance. There are predictable spectral trajectories associated with forest disturbances and related recovery after disturbance. A key feature of this research is linkage with FIA data to determine its utility in these analyses. To that end, meetings have been held with key FIA personnel, and formal memoranda of understanding (MOUs) are being developed to allow use of the FIA data to explore the possibility of relating changes in spectral properties of Landsat data over time to changes in forest biomass.

Masek and Cohen also met with two national-level FIA program managers to discuss the use of FIA data in the NACP. Those discussions are continuing, with the goal of more direct involvement of FIA personnel in the NACP.

Objectives for the Coming Year

The national disturbance mapping project will move from the radiometric testing stage to full implementation, with delivery of radiometrically calibrated datasets to a broad user community. Several different strategies will be tested to use these calibrated data to detect and characterize forest disturbances across several regions of the U.S. The Mid-Atlantic project will obtain FIA plot data and begin to link these with spectral changes associated with forest disturbance. The discussions with national FIA program managers will continue, as work continues toward a more direct engagement of the FIA and more effective use of FIA data in the NACP.

Task 900-37-172: **Phytoplankton Biomass, Primary Production, and Surface Dynamics from Ocean Color Sensors in the Southwestern Atlantic and Southern Oceans**

Goddard Visiting Fellows: Carlos Garcia and Virginia M.T. Garcia

Collaborators: Charles McClain (GSFC), Sergio Signorini (GSFC), Mauricio Mata (FURG/Brazil), Adriana Gonzalez-Silveira (UABC/Mexico)

Abstract

Satellite color sensors allow the study of phytoplankton biomass in the oceans on a large scale through pigment detection. However, the accuracy of these estimates depends upon application of reliable bio-optical algorithms. Surface pigment concentration (specifically, chlorophyll-*a*) and upwelling spectral radiance measurements were carried out between 1995 and 2004 during 15 oceanographic cruises in various water types, in the Southwestern Atlantic and Southern Oceans (1.8°-72° S and 18.5°-60° W).

These included Brazilian coastal waters, open ocean waters, and Antarctic waters. Empirical algorithms have been produced for each region and for a combination of all datasets. Results from coastal waters under influence of the La Plata River (on the Argentinean shelf) and Antarctic Peninsula tip regions will require other approaches, such as application of semi-analytical algorithms. An area from the Southwestern Atlantic, where there is a confluence of two western boundary currents, the Brazil and Malvinas Currents, has been selected to examine spatial and temporal chlorophyll-*a* variability, through ocean color data. Chlorophyll values were extracted from Sea-viewing Wide Field-of-View Sensor (SeaWiFS) images (9 km x 9 km resolution) from October 1997 to September 2002. A nonlinear model was used to fit the annual harmonic of the log chlorophyll concentration anomalies in the region. Analysis of the spatial variability of model parameters has shown the existence of a marked annual cycle (with different phases) at several locations in the region.

Description of Research

Several efforts have been made over the past few years to gather spectral radiometric data for ocean color chlorophyll algorithm development and remote sensing data validation. These observational experiments have—with NASA's SeaWiFS algorithms—contributed to making estimates of chlorophyll-*a* concentration from space. Bio-optical properties of seawater in the South Atlantic and Southern Oceans are poorly known, despite the efforts of some researchers. Bio-optical data gathered in the Southern Ocean under the Brazilian Antarctic Program (PROANTAR) since 1995 were used to generate a regional Southern Ocean chlorophyll algorithm. Bio-optical algorithm for mapping chlorophyll-*a* concentrations, based on the blue/green wavelength ratio, are being generated with this bio-optical dataset, and compared to the operational SeaWiFS algorithm.

A time series of monthly and weekly averaged, binned SeaWiFS images (provided by NASA) were examined for an ocean confluence region for two western boundary currents: the Brazil Current and the Malvinas (or Falkland) Current. This region is called the Brazil-Malvinas Confluence (BMC), and is located in the western Atlantic between approximately 30° S and 45° S. The amplitude of chlorophyll anomaly signal shows remarkable variability, which is strongly associated with upper layer stratification and mixing over the continental shelves. Analyses of power spectra at these specific locations have confirmed that mesoscale activity dominates over the BMC zones with signal periods of about 9-12 weeks. Ocean color data provide substantial information about signal variability at annual, semiannual, and other, higher frequencies that deserve further attention. Therefore, chlorophyll and primary production periodic cycles will be modeled, based upon the products derived from ocean color images provided by NASA (*i.e.,* from the Coastal Zone Color Scanner (CZCS), SeaWiFS, MODIS, etc.), and the space-time variability of chlorophyll will be verified.

The use of ocean color data provided by SeaWiFS will be investigated to estimate surface ocean currents in the BMC region. The SeaWiFS satellite data were received at Rio Grande. The method used to estimate the surface current fields is based on calculating the linear displacement of chlorophyll concentration features on the ocean surface from sequential SeaWiFS images by maximizing the cross-correlation within windowed portions of the images.

Accomplishments during the Reporting Period

Considerable effort has been spent in processing bio-optical data gathered from research vessels on 15 different cruises in the Southwestern and Southern Oceans (SwASO) between 1995-2003. The spatial bio-optical SwASO dataset covers a variety of biogeochemical regimes, which vary from the oligotrophic waters in the South Atlantic gyre to the coastal waters influenced by La Plata discharge. Several sampling stations are also located in the Southern Ocean. The measured (*in situ*) and satellite (SeaWiFS) spectral water leaving radiances were compared using Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies (SIMBIOS) and GSFC and other NASA facilities. The exercise demonstrated that SeaWiFS is performing very well in the South Atlantic Ocean, except in the Antarctic and La Plata regions. Time was spent preparing for two cruises for the austral summer,

and one in Antarctic waters, and one in the La Plata River coastal zone. The cruises were successfully conducted during January-February 2004.

Objectives for the Coming Year

Significant effort will be expended modeling chlorophyll periodic cycles in the BMC region, based upon the products derived from ocean color images provided by NASA sensors (*i.e.,* CZCS, SeaWiFS, and MODIS). A search has begun for sequential SeaWiFS and/or MODIS images to compute velocity fields using the maximum cross-correlation technique (Garcia and Robinson 1989). Attempts will be made to match satellite and drifter-derived surface currents. After returning to Brazil, another Antarctic cruise will be undertaken to continue oceanographic research in the area but with a strong emphasis on biogeochemical processes along the Patagonian shelfbreak.

Task 900-37-172: **Time-Variable Gravity from Ground to Satellites and its Relation to Global Geodynamics**

Goddard Visiting Fellow: Jacques Hinderer

Collaborators: Frank Lemoine (GSFC), Richard Ray (GSFC), Ben Chao (GSFC), David Crossley (Saint Louis University, MO), Jean-Paul Boy (EOST Strasbourg, France)

Abstract

Work under this task focuses on the potential use of high-quality surface gravity measurements made with superconducting gravimeters (from the Global Geodynamics Project (GGP) network) to validate and calibrate satellite gravity observations obtained from missions such as the Gravity Recovery and Climate Experiment (GRACE). An important corollary of this work is to estimate continental hydrology contributions to such measurements. Early results, using recently released monthly gravity solutions from GRACE applied to a specific zone in Europe, show that there is a clear, coherent, annual signal that is compatible with gravity surface measurements and hydrological predictions. Some work was initiated with hydrologists at GSFC to exploit GRACE data for water storage estimates. In addition, longer-term GGP data sets of surface time-variable gravity are being analyzed to provide better insight into some specific global geodynamics (*e.g.,* fluid core resonance, thermal tides, long-period zonal tides, and polar motion).

Description of Research

There are two major foci for work performed under this task. One is to examine differences between surface gravity observations (especially using the GGP sub-network in Europe) and GRACE satellite data with respect to calibration, validation, and data comparisons. The second is to continue a detailed analysis of long data sets from worldwide GGP stations to provide better constraints on the Earth's global dynamics and structure. These research areas are important for any time-variable determination of the Earth's gravity field derived from satellite data, since they will appear in corrections to these data from, *e.g.,* solid tides, thermal tides, ocean tides, and polar motion.

Accomplishments during the Reporting Period

For any Earth-sensing space mission there is a need to calibrate sensors and to validate the space-based measurements using simultaneous, ground-based, *in situ* measurements. Different aspects related to characterization and analysis of satellite gravity data obtained from the Challenging Mini-Satellite Payload (CHAMP) and GRACE have been investigated using surface measurement data obtained from the GGP. Preliminary results from a recent comparison done for a degree-truncated one-year span of CHAMP data and observations from superconducting gravimeters (SG) in Europe, Japan, China, and South Africa are promising in that common features from space- and ground-based measurements are clearly identified. More specifically, a test study showed that there is a clear annual signal that appears in an empirical orthogonal function (EOF) decomposition of all

the SG records. This signal of a few tens of nm s^{-2} being coherent over length scales of several hundred of km may provide a potential test signal with which GRACE data can be compared. This annual signal may be related to continental hydrology effects by showing the agreement between surface gravity observations and those inferred from a recent global scale hydrology model that includes contributions from soil moisture and snow.

After the release of the first GRACE monthly solutions (April-May 2002 to October 2003), the global gravity field solutions were converted gravity grids of suitable resolution for the same zone in Europe as was used in the earlier study. Different truncation levels were applied to the data and the same EOF decomposition that was used earlier was applied. There is a clear, coherent, annual signal similar to that found earlier (*i.e.,* high in winter, low in summer). A higher truncation level is optimal for this analysis, and higher degrees show spurious signals, at least on the global scale. As a result, in terms of current GRACE data processing, length scales of 400 km lead to unacceptable time-variable gravity solutions, regardless of the geographical zone being examined. There also appears to be a trend in the data also visible on global maps, the origin of which is still unknown.

Objectives for the Coming Year

The next step in the ground-orbit comparison project will be to assemble the GGP ground data for the same period and to perform the EOF decomposition of the gravity changes, which will provide the first direct comparison/validation between GRACE data and ground observations.

With regard to hydrological contributions, data sets for global models of continental hydrology have been updated and will be used to estimate the gravity loading contribution both at ground level and from satellites for the same observing period. This will provide the basis to identify this signature in both GRACE and GGP data. An important corollary of this study in Europe is to verify to which length scale GRACE data can be used in terms of hydrology research. Some specific hydrology-related questions on gravity data will be addressed in collaboration with hydrologists at GSFC. In particular, the climatic forcing of some of the largest basins in Europe will be estimated and the gravity time changes induced by the water storage will be evaluated at the ground-based GGP stations and from the GRACE satellites, taking into account the spatial averaging naturally done by the satellite measurements.

Other work will be done to further investigate the gravity signature of some global-scale geodynamical processes obtained from GGP network data, taking advantage of the worldwide character of the network and the extremely high sensitivity of the data. Some specific research areas, already under investigation, include:

- The free core nutation (FCN) resonance in gravity using all the GGP stations to perform a global inversion, using a recently developed Bayesian approach to refine the constraints on the eigenperiod and damping of this free rotational mode of the Earth.

- The impact of thermal tides on gravity, as these tides show an anomalous behaviour as compared to purely gravitational tides. The rationale for this work is the fact that there are thermally driven tides in the atmosphere that load the Earth and alter gravity differently. Recent models for these tides, developed at GSFC, will be considered, and the associated loading at the GGP stations will be computed and compared to observations.

- The gravity loading effect due to long-period ocean tides, as several studies have shown how GGP observations of the major diurnal and semi-diurnal tides can help in discriminating global ocean models from satellite altimetry and/or hydrodynamic modeling. This study will be extended to the long-period tides that are commonly observed in SG data because of their low instrumental drift.

- The polar motion-induced gravity, as the SGs are sufficiently stable in time to be capable to retrieve the gravity effects due

to the Earth's polar motion. It is important to determine the Earth's transfer function at a specific low frequency (due to the

- Chandler component) to better assess the Earth's rheology outside the seismic frequency band where most attenuation observations originate.

Task 900-37-172: **Goddard Visiting Fellow**

GEST Investigator: Roger H. Lang

Collaborator: David LeVine (GSFC, Code 975)

Abstract

The research during this sabbatical appointment was directed towards the study of scattering and propagation of waves in vegetation. Included in this work was the development of algorithms for microwave scattering and propagation in vegetation, and the design and construction of a truck mounted radar/radiometer system for measurements of joint active/passive L-band data.

Description of Research

During this sabbatical stay at GSFC, from 1 September 2004 to 30 April 2004, research was performed in three areas. The first was to develop algorithms for microwave scattering and propagation in vegetation. As part of this activity the investigator organized a session on "Scattering and Propagation of Waves in Vegetation" at the USNC/URSI Radio Science Meeting in Boulder, CO from 5-8 January 2004. In that session two papers on this topic were presented by co-authors [Utku, O'Neill, Tsegaye, and Seker 2004; Lang and Errico 2004]. The papers were related to the effect of leaf curvature on L-band backscattering from corn and long-distance propagation in forests. A GEST seminar was presented [Lang 2003], as was a Brown Bag Seminar [Lang 2004a] on similar topics. The GEST seminar was an overview of the investigator's past modeling and measurement work on backscatter from vegetation; the Brown Bag Seminar discussed some new research on the use of L-band radiometers to measure biomass. In particular, a partial solution to the mixed pixel problem was presented. During this period, the investigator also acted as a co-editor of a special section entitled "Foliage Penetration", which was published in the April 2004 issue of the Institute of Physics journal *Waves in Random Media.* This issue also included a paper [Lang 2004b] discussing the effect of rough surfaces on backscattering from forested areas.

In addition to this work, the investigator also was involved in the design and construction of a truck mounted radar/radiometer system. The purpose of the system was to develop remote sensing algorithms using joint active/passive L-band data. These algorithms will be implemented on the proposed Aquarius and Hydros L-and active/passive satellite sensors. Finally, work continued on the measurement of the dielectric constant of seawater. Results of this work were presented at a workshop on this subject at the Naval Research Laboratories at the Stennis Space Center in Mississippi [Lang 2004c].

Objectives for the Coming Year

As Dr. Lang's fellowship period at GEST has ended, there are no objectives for the coming year.

Task 900-37-172: **Development of Comprehensive Antarctic Magnetic Digital Anomaly Map using Satellite and Near-Surface Magnetic Data**

Goddard Visiting Fellow: Dan Lubin (on leave from the Scripps Institution of Oceanography)

Collaborator: P. Taylor (GSFC)

Abstract

Regional magnetic signals from the Earth's crust are strongly masked by the core field and its secular variation components; they are therefore difficult to isolate in satellite measurements. In particular, the unmodeled effects of the strong auroral external fields and the complicated behavior of the core field near the geomagnetic poles conspire to greatly reduce the crustal magnetic signal-to-noise ratio in the Polar Regions relative to the rest of the Earth. Spectral correlation theory can be used to filter static lithospheric anomalies and core field components from the dynamic external field effects. To help isolate regional lithospheric anomalies from core field components, the correlations between magnetic anomalies derived from the Challenging Minisatellite Payload (CHAMP) and the pseudomagnetic effects inferred from gravity-derived crustal thickness variations can also be exploited. Employing these procedures, the CHAMP magnetic observations were processed for an improved magnetic anomaly map of the Antarctic crust. Relative to the much higher altitude Ørsted and noisier Magsat observations, the CHAMP magnetic anomalies at 400 km altitude reveal new details on the effects of intracrustal magnetic features and crustal thickness variations of the Antarctic.

Description of Research

Research activities under this task focus primarily on the geopotential fields of the Earth's lithosphere from satellite, airborne, shipborne, and terrestrial observations. Satellite potential surveys, in particular, offer a unique window on the regional geology over large inaccessible regions (*e.g.,* the Arctic, the Antarctic, the Amazon basin, etc.) in terms of nearly uniformly distributed observations collected over relatively short periods of time. For example, Earth orbiting satellite magnetometer observations Earth from the Polar-Orbiting Geophysical Observatory (POGO), Magsat, Satelite de Aplicaciones/Cientifico-C (SAC-C), and Ørsted missions provide significant constraints for understanding regional petrological variations of the crust and upper mantle, and crustal thickness and thermal perturbations.

Work is being done to improve the utility of these observations for lithospheric studies. For example, satellite observations are commonly represented and analyzed as predictions from global spherical harmonic models. However, these predictions usually have relatively poor sensitivity for the higher-frequency anomaly details that are available in the local data coverage. To exploit the local anomaly details in the track coverage as fully as possible, procedures are being investigated to represent and analyze satellite geopotential field observations over spherical patches of coverage. These procedures include the use of equivalent point source inversion for estimating spherical coordinate anomaly continuations, interpolations, differential reductions-to-pole, gradients, correlations, and other components. The GEST investigator has also adapted equivalent point sources to Gauss-Legendre quadrature integration for relating satellite magnetic and gravity anomalies to arbitrary spherical coordinate distributions of lithospheric magnetization and density.

Accomplishments during the Reporting Period

Research has involved developing an Antarctic magnetic anomaly map from all available magnetic data, including those from satellites, ship and airborne instruments, and ground surveys. This is a part of the Antarctic Digital Magnetic Anomaly Project (ADMAP) that has been performed in cooperation with a number of international scientific communities. Long-wavelength magnetic anomalies from near-surface data were seriously corrupted due to gaps in data

coverage, errors in data leveling, and correcting for secular core field variations. However, such error can be reduced by the use of satellite-based magnetic observations, because they provide relatively uniform regional coverage and are taken over periods where secular variations of the core field are negligible. In particular, Antarctic satellite magnetic observations can be used to develop a geologically coherent reference anomaly field to help fill gaps in coverage. In addition, these observations can improve the merger of disparate near-surface surveys into regional- and continental-scale composites. The work used joint inversion between the satellite and the near-surface data, and proved that more accurate and lower-altitude satellite magnetometer data lead to better predictions over the gap in coverage [Kim *et al.* 2003]. Additionally, a magnetic model was developed from the effects by the crustal thickness variations over the Antarctic using spherical cap harmonic expansions. This model was developed to extract the regional long wavelengths that were coupled with the secular core field or the ionospheric components from CHAMP satellite magnetometer data.

Work also resulted in the development of a CHAMP satellite magnetic anomaly map over Kursk (Russia), which is known as one of the largest magnetic anomalies on Earth. This anomaly contains the largest-known reserves of iron ore in the world. Recently, Dr. P. Taylor, (GSFC) and the GEST investigator worked with European colleagues studying satellite-derived magnetic fields and the gravity field over South and Central Finland and the Pannonian Basin. The object of this study was to determine if regions having significantly different crustal thickness would display different magnetic anomaly values at satellite altitude. It was found that both regions displayed significantly higher than normal (*i.e.,* world-average) heat flow values. The CHAMP gravity anomalies for South and Central Finland were associated with a relatively thinner part of the crust and the central Baltic Sea, but the positive gravity anomaly over the Pannonian Basin was correlated with the negative magnetic anomaly. In the Pannonian Basin the Tertiary subduction of the Eurasian plate produced the crustal thinning, with the greatest amount found in the central part of this basin. The anomalous high-density body resulted from east-west compression with subsequent lithospheric mantle upwelling.

Objectives for the Coming Year

The coming year will be dominated by two major new activities. The first of these is to complete the development of a model to represent the Antarctic magnetic anomaly field using spherical cap harmonic analysis. This task involves cooperation with European colleagues to develop the harmonic model using all available magnetic data below 60° S in Antarctica. This model will be contributed to the geophysical/tectonic community to give unique insight into the interpretation and reconstructions of Earth's historical plate tectonics. The second activity will be to develop a magnetic field anomaly map of Mars using recent Mars Global Surveyor (MGS) data. The MGS magnetic data are easily available at GSFC, and the same tools and available expertise can be used to generate maps of Mars' magnetic field. The magnetic field anomalies in the northern hemisphere of Mars are so weak and vague that general spherical harmonic expansion models may not fully represent the features in this region. Spectral correlation analysis will be expected to enhance the magnetic features in northern Mars. A number of ongoing activities include geopotential modeling of Iceland and satellite gravity-derived crustal thickness modeling in Greenland.

Task 900-37-172: **Parallel Numerical Kernels for Climate Models Based on the Object-Oriented Features of Fortran 90 and the Parallel Extensions of Co-Array Fortran**

Goddard Visiting Fellow: Robert W. Numrich

Collaborators: Tom Clune (GSFC), V. Balaji (GFDL)

Abstract
Standard methods for developing high-performance parallel computing applications are awkward to use, do not scale well to large numbers of processors, and are somewhat out of touch with modern applications. New approaches to parallel programming are needed for machines with tens or hundreds of thousands of processors, which will be available by the end of the decade. This project investigates the effectiveness of one of these new approaches, called "Co-Array Fortran" (CAF).

Description of Research
Work under this task is done to investigate the use of alternative parallel programming models for applications that are important to the Earth sciences community. To expand existing applications to new architectures that will be developed in the next few years, one must go beyond existing parallel programming models. The level of abstraction must be raised to make it easier to define computational data structures and algorithms specific to particular disciplines. The details of parallel programming must be made easier for scientists to use, and a way is needed to combine related applications in a natural way. CAF, a simple extension to Fortran 90, provides a mechanism to accomplish these goals.

Accomplishments during the Reporting Period
CAF [Numrich and Reid 1998] is a simple extension to Fortran 90 that provides a simple syntax to define parallel data structures and to express parallel algorithms. It is one of a triad of alternative programming models based on simple extensions to existing languages. The idea behind these extensions is that a mechanism for pointing to data structures in remote memory from data structures in local memory is sufficient to provide an efficient parallel programming model. The other members of the triad are Unified Parallel C [Carlson *et al.* 1999] (an extension to the C language), and Titanium [Yelick *et al.* 1998], an extension to Java. Each of these extensions uses syntax that makes sense for the particular language, but the underlying programming model is essentially the same.

The power of CAF comes from combining it with the object-oriented features of Fortran 90. It raises the level of abstraction by defining named derived types (similar to classes), defining constructors and destructors that know how to build these structures, and using generic interfaces to define procedures (similar to methods), that manipulate data within the data structures. By declaring these data structures to be co-arrays, they become parallel data structures. The constructors distribute data across memory and the procedures carry out algorithmic tasks in parallel, based on the underlying distribution defined by the co-array. With a well-designed library, similar to a class library, the application programmer can write code at a very high level of abstraction, leaving many of the complicated, messy details of parallel programming to be handled by the library.

The Earth sciences community has approached this problem by defining a component-based framework called the Earth System Modeling Framework (ESMF). It has defined a large number of abstract data structures (such as fields, grids, components, and couplers) that encapsulate parallel data structures, provide procedures for manipulating data within those structures, and provide communication procedures to transfer data. The communication layer is based on the Message-Passing Interface (MPI) that lies at the lowest hierarchical level of the ESMF design.

The ESMF design has been analyzed to see how CAF might be used to advantage, either to make the design more efficient or to make it easier for

the programmer to use. Investigations have addressed how the team concept might be used to represent components. The team concept was defined in CAF specifically to support this kind of application. Preliminary conclusions are that teams can handle some cases supported by ESMF, but that some new extensions may need to be added to CAF to handle other cases. Another place to apply CAF is in defining co-array data structures to be used by the coupler components to communicate between application components; this changes the communication model for ESMF. Rather than having the communication layer buried at the lowest level, the CAF model brings communication to the highest level associated with the data structures themselves. Such a change must be done very carefully so as not to lower the level of abstraction. A third application for CAF is within each component to replace MPI communication with CAF communication.

Because the ESMF model is very complicated, the use of CAF on a much simpler problem as a proof of concept is being investigated. Implementing the shallow water equations [Arakawa and Lamb 1977] in CAF has begun. Data structures are being defined along the lines of the data structures used by Balaji [2001] and by ESMF. They are made co-array structures and the data distribution defined through constructors that distribute data for a co-array. Defining differential operators are being defined as necessary for the problem whose form will depend on the grid types used for the problem. The code will be much simpler than the corresponding MPI code. It will perform much more efficiently and will scale much better on machines with large numbers of processors [Burton *et al.* 2001].

Application programmers will use a new programming model only if it is standardized and portable to many different machines. To address this issue, an open source, portable version of CAF has been installed on the Hewlett-Packard Alpha Super Cluster system at GSFC, and compiler evaluation has begun.

Objectives for the Coming Year

In the coming year, the performance of CAF on the parallel machines at GSFC will be evaluated. A complete CAF implementation of the shallow water equations is expected. Recommendations will be made for defining parallel data structures based on co-arrays, differential operators for those data structures, and communication primitives based on co-array syntax. A recommendation will be generated on how to support the component architecture within the CAF programming model.

Task 900-37-172: **Modeling Satellite Magnetic Data for the Earth and Mars**

Goddard Visiting Fellow: Kathy Whaler

Collaborator: M. E. Purucker (GSFC)

Abstract

Techniques originally developed to treat the terrestrial crustal magnetic field measured by orbiting satellites can be applied to magnetic data collected by the Mars Global Surveyor. These techniques include producing models of the magnetic field itself, and of magnetization distributions in the near surface capable of explaining the measured magnetic field. Recent refinements to the methods have been applied to the best available satellite data sets for both planets. The results compare favorably with previous methods. The Martian models show evidence for structural and tectonic features and for “polar wander” of the magnetic field and magnetic field reversals in the first approximately half-billion years of Martian history, during which its dynamo operated. A history of magnetization and de-magnetization events that could be responsible for prominent features of our models is being produced.

Description of Research

The conjugate gradient (CG) algorithm has proved an immensely useful tool for inverting satellite magnetic data. It was first applied by the GSFC

collaborator on this work to terrestrial crustal anomaly data in a 1996 publication. It allows the inversion of large satellite data sets, since the 'footprint' of each datum on the planetary surface is small (*i.e.*, each satellite datum depends on the magnetization of a disk of crustal material whose center is directly below the satellite's position, and whose perimeter subtends a small angle with it). Prior to the inception of this work, some preliminary models of the terrestrial magnetic field and magnetization using CG had been constructed, and work had begun on Martian models. In contrast to Purucker *et al.*'s earlier work, magnetization is modeled as a continuously varying function of position, rather than as a collection of crustal blocks, each of which contains an embedded magnetized dipole. The magnetic field models developed here retain the resolution of the original data and do not involve the subjective choice of a maximum wavelength retained in the solution. However, equivalent spherical harmonic coefficients can be computed from them for comparison with the usual solutions.

The research goal, then, is to produce the best possible Martian and terrestrial magnetic field and magnetization models, and to provide structural and tectonic interpretations of them. In the terrestrial case, satellite data can be augmented by airborne, marine, and ground data to provide higher resolution over certain areas. As part of the study, the methods have been tested on synthetic data, the influence of (and best choices for) the various 'tuning' parameters associated with the numerical methods have been investigated, and several different data sets have been evaluated, some comprising only the radial component magnetic field data (thought to be less severely contaminated by external magnetic fields associated with solar activity) and some with full three-component vector data.

Accomplishments during the Reporting Period

Considerable progress was made during the tenure of the visiting fellow at GSFC last year, as noted in Whaler and Purucker [2003], which addressed preliminary Martian magnetization models. This work treated only radial component data; the latest models include all three components and are based on an improved data set. The preliminary models showed implausibly high magnetizations near the poles; this has now established to have been caused by a few high amplitude measurements in the earlier data set (rather than instabilities in the numerical calculations near the poles), possibly reflecting severe external field contamination. The new models have realistic amplitudes near the poles. Despite the severe non-uniqueness associated with deducing crustal magnetization from magnetic field data, the new models correlate extremely well with the results of using very different modeling methods. A comparison of power spectra shows that the new magnetic field models have a very similar morphology to previous models at longer wavelengths, but less power in smaller-scale features. Since they fit the data to a very similar level, the reliability of high-degree and -order coefficients of spherical harmonic models is being questioned.

Work began on a presentation made at the second Challenging Minisatellite Payload (CHAMP) scientific meeting in September 2003, which involved merging the latest terrestrial satellite data with marine and aeromagnetic data over the North Atlantic, Europe, and the Arctic. The models will be used to investigate the relative amounts of remnant and induced magnetization, to determine if there is evidence of movement of the Iceland hot spot, and to examine the magnetization contrast across features such as the Tornquist-Tesseyre line separating Paleozoic from Precambrian Europe. Calculations of the correlation lengths of the magnetic field and magnetization are underway.

Objectives for the Coming Year

As Dr. Whaler's fellowship period at GEST has ended, there are no objectives for the coming year.

Task 910-37-172: **Aerosol Radiative Forcing of Climate**

Goddard Visiting Fellow: Maeng-ki Kim

Collaborator: William K. M. Lau (GSFC)

Abstract

Research has focused on understanding dynamical effects on regional and global climate change induced by aerosol radiative forcing for five main aerosols using the Global Modeling and Assimilation Office (GMAO)'s finite-volume General Circulation Model (fvGCM) Microphysics of Clouds, with the Relaxed Arakawa-Schubert Scheme (McRAS). Absorbing aerosols were shown to have a significant semidirect effect on regional climate change. Dryness due to atmospheric heating and diffusion due to surface cooling within the planetary boundary layer (PBL) are important in determining the magnitude of the semidirect effect.

Description of Research

Aerosol forcing and response have considerable uncertainty because of poorly defined optical properties and uncertainties in aerosol vertical distribution. Recently, much progress has been made in aerosol transport models, such that they now provide quite realistic three-dimensional structures of aerosol properties for various aerosol types despite significant uncertainty. Aerosols may play an important role in global warming by absorbing solar radiation, warming that augments that due to the presence of carbon dioxide. This study focuses on the dynamical effect on climate change induced by absorbing aerosols, based on a realistic 3-D distribution of aerosols and related physical phenomena.

Accomplishments during the Reporting Period

Climate impacts induced by aerosol radiative forcing were studied using several fvGCM/McRAS simulations. Several primary model experiments—with and without aerosols—were performed using various combinations of aerosol forcing. Five types of aerosols were prescribed, using three-dimensional monthly mean data obtained from the Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model. Aerosol extinction coefficient, single scatter albedo, and asymmetric factor were also considered in the radiation package as a function of relative humidity and wavelength. It was found that the atmospheric circulation change induced by absorbing aerosols could contribute to the observed magnitude of regional cooling and warming as an additional regional climate change mechanism. Black carbon and dust play especially important roles in surface climate change in the Asian continental region, implying that this change may lead to a change in the onset of the Asian monsoon.

Objectives for the Coming Year

A primary objective for the coming year is to understand the response of the PBL to the different aerosol forcings using GCM simulations with prescribed sea surface temperature (SST) and ocean mixed-layer models. This comparison will provide the insight as to the role of the PBL on the semidirect aerosol effect.

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Educational Programs

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Educational Programs

The summer of 2003 marked the third year GEST has managed three GSFC on-site educational programs: Visiting Student Enrichment Program (VSEP); Graduate Student Summer Program (GSSP); and NASA Summer School for High Performance Computational Earth and Space Sciences (HPC). Despite financial constraints and the loss of the Goddard Coastal Research Fellowship Program, all programs were successful and provided invaluable experiences to the students. GEST also continued its Graduate Fellowship program at UMBC, and initiated an outreach relationship with a Baltimore museum.

Visiting Student Enrichment Program (VSEP)

The VSEP is open to high school, undergraduate, and graduate students in the computer sciences, mathematics, and physical sciences, and is sponsored jointly by GSFC's Earth and Space Data Computing Division (ESDC) and GEST. The program focused on teaching students how to do research, write reports in the style preferred by NASA, how to write an abstract (which were compiled at the VSEP student seminars), how to create a scholarly poster, and how to create a computer-driven slide presentation.

VSEP 2003 supported eighteen students, chosen from 112 applications. The student population included two master's degree-level graduate students, twelve undergraduate students, and four high school students. Of the eighteen students, only six were local to the GSFC area, with students traveling from as far away as Alaska. Students were housed in apartments at the University of Maryland, College Park, and were shuttled to GSFC daily. Planned events for students included eight lectures, three report-content classes, two field trips (*i.e.,* to the NSA Cryptology Museum and the Wallops Flight Facility), and two social activities.

Changes were implemented in this year's program to meet the needs of the twenty-first century student. Students had individual meetings with the program coordinator in the third week of the internship to identify students' needs and concerns with their projects. Weekly updates were then implemented to ensure the students' success in the program. Students also went through a "critique circuit" before their poster session in August. Once approved, VSEP had the opportunity to print the students' poster on a large-format printer at no cost. This allowed students to present their research in a manner consistent with today's conference standards.

The projects completed during VSEP 2003 included:

Fluorescence Imaging to Assess Carbon & Nitrogen in Vegetation, Velina Daleva

Integration of Matlab and Linux Clusters, Joan Puig Giner

Mass Storage Assessment, Carla Ball

Providing Near-Real-Time Statistical Metrics of Parallel-Multi-Processor Machines via Visual Graphics for the NCCS Community, Richard Dill

Preprocessing of Data for Use in Image Registration Techniques, Lisa Johansen

Solving the Potential Flow Problem with Finite Elements, Kimberly Sayles

Quantum Mechanical Simulations on a Beowulf Cluster, Nathan Shupe

A Multilevel Preconditioner for Fast Methods of Data Assimilation, Jennifer Bailey

I/O Performance Analysis on Beowulf Clusters, Nathan Redding

Windows Nu Testing Transport Control Protocol Service, Derek Wagner

Quantum Chemistry Calculations, Juri Yanase

A Parallel Implementation of Gradient Descent Image Registration, Matthew Wollenweber

Simulation of the Behavior of Water In A Closed Environment, Lida You

Facilitation of RDL Generation Processes and Event Messaging For the James Webb Space Telescope, Naveed Haghani

Use of Ion Engines in Large Orbital Maneuvers, Eric Samson

Tracing the Movement of Carbon Monoxide into the Arctic Using MOPITT, Amruta Sarma

Validating James Webb Space Telescope Flight Software, Winston Carter-Hawkins

Thus far, 200 applications have been received for the summer 2004 education program; a minimum of fifteen students are expected to be selected this year.

Graduate Student Summer Program (GSSP)

The intent of the GSSP is to encourage graduate students in the Earth sciences to conduct genuine research at GSFC that can be incorporated into their graduate theses or dissertations. The ten-week program is open to students in a master's or doctoral program. Each applicant must submit a proposal of the work they would like to do while at GSFC, and propose a GSFC mentor or research team with which they would like to work. The Goddard Coastal Research Fellowship Program was absorbed by GSSP this year, enabling students to be placed at any of the three Goddard institutions: Goddard Space Flight Center, Goddard Institute for Space Studies, and the Wallops Flight Facility.

The theme for the four-day seminar series that initiated the program was "Measurements and Modeling of Aerosols, Clouds, and Radiation." Twelve students were selected this year out of twenty-one completed applications. The student population included six doctoral students and six master's-level students, only one of which was local to GSFC. One student was selected to work at the Goddard Institute for Space Science (GISS) in New York City; three students were placed at the Wallops Flight Facility (WFF) on Wallops Island, VA, and the remaining students worked at GSFC. Individual meetings were conducted with each student two weeks into the program to monitor their progress, to assess their relationship with their mentor, and to see how well they understood their project and their role in it. These meetings were followed by visits to students at their workstations, although GISS and WFF students were reached by telephone. GSSP students were given the opportunity to participate in the field trips organized by VSEP, but they also had their own social activities. All students were required to present a twenty-minute seminar on the work they had completed during the ten-week program. The students' last requirement was to submit a paper to GEST; all papers are available for public review on the GEST Website (http://gest.umbc.edu/student_opp/2004_gssp.html). Notably, four students' GSSP papers were accepted for publication in scientific journals, one of which was co-authored by a GEST faculty member who served as a mentor. What follows is a list of the projects completed during GSSP 2003:

The Regional and Diurnal Variability of the Vertical Structure of Precipitation Systems in Africa, Based on TRMM Precipitation Radar Data, Teferi Dejene

A New Approach to Simulate a Realistic Spatial Structure of Cloud Droplets, Michael L. Larsen

Landscape Patterns and Dynamics in the Boreal Forest, Central Siberia, Jessica Brooks

Correcting the Scan Angle Dependence in HARLIE Data, Afusat Dirisu

Spatial Data Accessibility and the Semantic Web, Femke Reitsma

Lightning NOx and Tropospheric Ozone Formation in the NASA GISS GCM, Amanda Hopkins

A Calibration Approach for the Fully Polarimetric Airborne C Band Microwave Radiometer: Theoretical Basis and First Field Results, Hanh Pham

Grid Rainfall Disaggregation Toward a Patch-Based Ensemble Kalman Filter For Soil Moisture Data Assimilation, Filip Jagodzinski

Validating Modeled KWAJEX Convective Systems, Thomas O'Halloran

Processing GPS Data from the NASA Experimental Advanced Research Lidar (EAARL),
Deepak Mishra

Enhancement of Technical Systems on the Experimental Advanced Airborne Research Lidar, Conan Noronha

Using the Moderate Resolution Imaging Spectroradiometer (MODIS) to Estimate Phytoplankton Processes in the Ross Sea, Antarctica, Jill Peloquin

The application pool for summer 2004 is about 40, of which nine students will be selected this year. The seminar series will be held 9-11 June 2004, and will feature a variety of lectures from scientists in the Earth Sciences Directorate to expose students to all areas of GSFC-based Earth science research.

NASA Summer School for High Performance Computational Earth and Space Sciences (HPC)

The HPC Summer School is a three-week intensive course open to doctoral students in the Earth or space sciences who incorporate large-scale numerical modeling on massively parallel architectures into their dissertation research. The ESDC and the Computational Technologies Project (CT) run this highly competitive program. GSFC is home to world-class computing facilities, which include a 1392-processor HP/CPQ SC45 alpha cluster, a 384-processor SGI Origin 3800, a 512-processor commodity cluster, and numerous middle-sized supercomputing platforms. Local GSFC scientists from the ESDC and invited speakers from around the country are instructors for the course. Lectures were presented on developing software for scalable architectures and computational fluid dynamics and particle methods. Hands-on parallel computer training and small-group tutorial sessions were also provided. Fifteen students participated in the 2003 HPC Summer School, of which three were from the University of Maryland, College Park, five were from universities within the tri-state area (*i.e.,* Maryland, Virginia, and Washington, DC), and the remaining students represented institutions from across the country. The farthest state represented was Washington. Students were housed at the University of Maryland, College Park, and were provided with daily transportation to GSFC. At the end of the program, all students were given the opportunity to give a 30-minute presentation on their dissertation research.

GEST Graduate Fellowships

Two GEST graduate fellowships were awarded, one in the Physics Department at UMBC, and the other in the Department of Computer Science and Electrical Engineering.

Eric A. Eaton was selected from the UMBC Department of Computer Science and Electrical Engineering. He has a B.S. degree from UMBC in Computer Science and is beginning studies for a Ph.D. in applications of artificial intelligence. His interests lie in the areas of medical diagnostic and scanning systems, and human-computer interactions through intelligent interfaces and intelligence agents.

William A. McClintic, Jr. was the second recipient of the GEST graduate fellowship. He was a new Ph.D. candidate, having enrolled in UMBC's Atmospheric Physics program in the fall of 2003.

Maryland Science Center Collaboration

Anathea Brooks and Daniel Laughlin visited the Maryland Science Center (MSC) in Baltimore's Inner Harbor in August 2003 to meet with Flavio Mendez, Director of MSFC's SpaceLink, and to assess the feasibility of GEST scientists participating in exhibitions for the new wing of the museum, which is to be a dedicated Earth sciences exhibit hall, and scheduled to be open to the public in June 2004. Particular emphasis was placed on the contents of one display area to be called TerraLink, which will provide real-time data and interactive media via direct TV links, video feeds, or Websites, to explore cutting-edge research in

the Earth sciences, including such topics as natural hazards, global climate change, biodiversity, hydrology, atmospheric science, and geological science.

GEST faculty and staff will be able to participate in two main programs. The first is "Science Person of the Month," highlighted on the MSC Website. This program also calls for participating with the public for one Saturday. The objective is for young people to learn about the work scientists do, the training that was required, and to inspire the pursuit of Earth sciences as a career. The second vehicle is "Teachers' Thursdays", held monthly, to provide K-12 teachers with a general review of a specific topic in Earth science, along with possible lesson plans for classroom use. Several GEST faculty members are already prepared to participate in each of these programs once the Earth sciences exhibit hall opens.

L. Anathea Brooks and Marci Delaney

Short-Term Visitors

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Short-Term Visitors

GEST facilitates collaboration between scientists at GSFC and those at other research institutions to support collaborative work at GSFC, field locations, and external conferences. This program has hosted a wide variety of visitors, from graduate students to research support staff, to senior researchers. Many of our visitors are invited speakers for established seminar series, while the younger visitors typically come to GSFC for hands-on training or to obtain data for their own research at their home institutions.

During the past year, those scientists who visited GSFC under the auspices of GEST include:

Visitor	Affiliation	Code Visited
Agbaria, Adnan	University of Illinois, Urbana-Champaign	900.1
Balaji, V.	NOAA	913
Bauer, Susanne	NASA GISS (Goddard Fellow)	900.1
Baumhefner, Dave	NCAR	910
Bras, Rafael	Massachusetts Institute of Technology	974
Carswell, James	Remote Sensing Solutions	912
Cess, Robert	State University of New York at Stony Brook	913
Chaikovsky, Anatoli	Belarus National Academy of Science	913
Chen, Jen Ping	National Taiwan University	913
Clothiaux, Eugène	Pennsylvania State University	913
Coble, Paula	University of South Florida	900
Davis, Douglas	Georgia Institute of Technology	910
DeZeeuw, Darren	The University of Michigan	913
Diab, Roseanne	University of Natal, South Africa	916
Duffy, Philip	Lawrence Livermore National Lab	910
Duncan, Bryan	École Polytechnique Fédérale	916
Ebert, Suzanne	University of Melbourne, Australia	974
Ghil, Michael	University of California, Los Angeles	910
Gombert, Dale	Astronomical Society of the Pacific	900.1
Gonçalves, Luis	University of Arizona	974
Halvorson, Joel	Science Museum of Minnesota	900
Jagodzinski, Filip	Villanova University	974
Karnieli, Arnon	Ben Gurion University, Israel	913
Kostinski, Alex	Michigan Technological University	913
Kuehn, Ralph	University of Wisconsin, Madison	912
Ladstaetter, Annette	University of Bremen, Germany	916
Li, Qing Bing	Harvard University	913
Llort, Xavier	GRAPHI, Spain	912

Visitor	Affiliation	Code Visited
Matichuk, Rebecca	University of Colorado	913
Mayer, Bernhard	German Aerospace Center	913
McFarquhar, Greg	University of Illinois, Urbana-Champaign	913
Nesbitt, Steve	Colorado State University	913
Pielke, Sr., Roger	Colorado State University	913
Pincus, Robert	NOAA-CIRRES	913
Queface, Antonio	Eduardo Mondiane University, Mozambique	913
Rosenfeld, Daniel	The Hebrew University of Jerusalem	913
Rudich, Yinon	Harvard University	913
Ruediger, Christoph	University of Melbourne, Australia	974
Santer, Benjamin	Lawrence Livermore National Laboratory	913
Savige, Cressida	University of Melbourne, Australia	974
Sekelsky, Stephen	University of Massachusetts	912
Skinner, Lizzy	Melbourne Water	974
Spitzer, William	New England Aquarium	900
Straub, Katherine	Susquehanna University	912
Su, Wenying	NASA Langley	913
Tedesco, Marco	Carrara Insitute of Applied Physics, Italy	975
Vandiver, Ray	Oregon Museum of Science	900
Waliser, Duane	State University of New York at Stony Brook	913
Walker, Jeff	University of Melbourne, Australia	974
Weissman, David	Hofstra University	912
Woodward, Paul	University of Minnesota	913
Wooster, Martin	King's College of London	913
Yoshizaki, Masanori	Meteorological Research Institute, Japan	912
Yu, Hongbin	Georgia Institute of Technology	913
Zeng, Xubin	University of Arizona	910
Zhang, Guang	Scripps Institution of Oceanography	913

Marci Delaney and L. Anathea Brooks

APPENDICES

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References

Alexander, M. A., J. D. Scott, and C. Deser (2000), Processes that influence sea surface temperature and ocean mixed layer depth variability in a coupled model, *J. Geophys. Res. - Oceans*, *105,* 16,823-16,842.

Anyamba, A., C. O. Justice, C. J. Compton, and R. Mahoney (2003), Seasonal to interannual variability of vegetation and fires at SAFARI 2000 sites inferred from AVHRR time series data, *J. Geophys. Res. – Atmos.*, 108(D13), 8507.

Anyamba, A., C. J. Tucker, R. A. Huete, and B. K. Boken (in press, 2004), Drought monitoring using coarse-resolution polar-orbiting satellite data, in *Agricultural Drought: Global Monitoring and Prediction,* edited by V. K. Boken, A. P. Cracknell, and R. L. Heathcote, Oxford University Press.

Arakawa, A., and V. Lamb (1977), Computational design of the basic dynamical processes of the UCLA General Circulation model, in *Methods in Computational Physics*, Vol. 17, 173-265.

Bacmeister, J., P. J. Pegion, S. D. Schubert, and M. J. Suarez (2000), An atlas of seasonal means simulated by the NSIPP 1 Atmospheric GCM, NASA technical memo 104606, Volume 17, Goddard Space Flight Center, Greenbelt, Md.

Balaji, V. (2001), Parallel numerical kernels for climate models, in *Developments in Teracomputing*: *Proceedings of the Ninth ECMWF Workshop on the Use of High Performance Computing in Meteorology*, edited by W. Zwieflhofer and N. Kreitz, 277-295, World Scientific Publishing, Singapore.

Becker, G., R. Muller, D. S. McKenna, M. Rex, K. S. Carslaw, and H. Oelhaf (2000), Ozone loss rates in the Arctic stratosphere in the winter 1994/1995: Model simulations underestimate results of the Match analysis, *J. Geophys. Res., 105*, 15,175-15,184.

Bell, T. L., and P. K. Kundu (1996), A study of the sampling error in satellite rainfall estimates using optimal averaging of data and a stochastic model, *J. Climate, 9*, 1251-1268.

Bell, T. L., and P. K. Kundu (2003), Comparing satellite rainfall estimates with rain gauge data: Optimal strategies suggested by a spectral model, *J. Geophys. Res., 108*(D3), 4121, doi:10.1029/2002JD002641.

Bell, T. L., P. K. Kundu, and C. D. Kummerow (2001), Sampling errors of SSM/I and TRMM rainfall averages: Comparison with error estimates from surface data and a simple model, *J. Appl. Meteorol., 40,* 938-954.

Bonan, G. B., *et al.* (2002), The land surface climatology of the community land model coupled to the NCAR community climate model, *J. Climate*, *15*, 3123-3149.

Burton, P., B. Carruthers, G. S. Fischer, B. H. Johnson, and R.W. Numrich (2001), Converting the halo-update subroutine in the MET Office Unified model to Co-Array Fortran, in *Developments in Teracomputing*: *Proceedings of the Ninth ECMWF Workshop on the Use of High Performance Computing in Meteorology*, edited by W. Zwieflhofer and N. Kreitz, 177-188, World Scientific Publishing, Singapore.

Carlson, W. W., J. M. Draper, D. E. Culler, K. Yelick, E. Brooks, and K. Warren (1999), Introduction to UPC and language specification, technical report, CCS-TR-99-157, Center for Computing Sciences.

Chou, M. D., *et al.* (2003), A Thermal infrared radiation parameterization for atmospheric studies, NASA/TM-2001-104606, *19*, 55.

Gatebe, C., M. D. King, A. I. Lyapustin, G. T. Arnold, and J. Redermann (in press, 2004), Airborne spectral measurements of ocean directional reflectance, *J. Atmos. Sci*., CLAMS Special Issue.

Held, I. M., and M. J. Suarez (1994), A proposal for the intercomparison of the dynamical cores of Atmospheric General Circulation models, *Bull. Amer. Met. Soc*., *75*, 1825-1830.

Higgins, R. W., Y. Yao, E. S. Yarosh, J. E. Janowiak, and K. C. Mo (1997), Influences of the Great Plains low-level jet on summertime precipitation and moisture transport over the central United States, *J. Climate*, *10*, 481-507.

Kiehl, J. T., J. J. Hack, G. B. Bonan, B. A. Boville, D. L. Williamson, and P. J. Rasch (1998), The National Center for Atmospheric Research Community Climate model: CCM3, *J. Climate, 11*, 1131–1149.

Kundu, P. K., and T. L. Bell (2003), A Stochastic model of space-time variability of mesoscale rainfall: Statistics of spatial averages, *Water Resour. Res., 39*, 1328, doi:10.1029/2002WR001802.

Lait, L. R., *et al.* (2002), Ozone loss from quasi-conservative coordinate mapping during the 1999-2000 SOLVE/THESEO 2000 campaigns, *J. Geophys. Res., 107*.

Lang, R. (2003), Modeling and measurement of microwave emission and backscatter from vegetation, paper presented at NASA/GSFC, GEST Visiting Scientist Seminar Series, December.

Lang, R. (2004), Measurement of the dielectric constant of sea water, paper presented at Workshop on Seawater Emissivity at L-Band, Naval Research Laboratories, Stennis Space Center, Mississippi.

Lang, R. (2004), Passive L-Band measurement of forest biomass, paper presented at Brown Bag Seminar at NASA Goddard Space Flight Center, Greenbelt, Md., March.

Lang, R. (2004), Scattering from a layer of discrete random medium over a random interface: Application to microwave backscattering from forests, *Waves in Random Media*, Vol. 14, S359-S391, April.

Lang, R., and S. Torrico (2004), Total attenuation through a two dimensional truck dominated forest, paper presented at USNC/URSI Meeting, Boulder, Col., January.

Lang. R., C. Utku, P. O'Neill, T. Tsegaye, and S. S. Seker (2004), The effect of leaf curvature in Active Electromagnetic modeling of corn canopies, paper presented at USNC/URSI Meeting, Boulder, Col., January.

Lau K. M., and H. Weng (2002), Recurrent teleconnection patterns linking summertime precipitation variability over East Asia and North America, *J. Meteorol. Soc. Japan*, *80,* 1309-1324.

Lawford, R. G., *et al.*, (accepted for publication, 2004), Advancing global and continental scale hydrometeorology: Contributions of the GEWEX Hydrometeorology panel, *Bull. Amer. Meteorol. Soc*.

Lawford, R. G., M. Manton, L. Martz, and T. Oki (accepted for publication, 2004), Remote sensing and indicators: Contributions of the Global Energy and Water Cycle Experiment (GEWEX) and its Water Resources Applications Project (WRAP), *Monitoring Tailor-Made IV,* MTM IV Conference Secretariat, Lelvstad, the Netherlands.

Lin, S. J., and R. B. Rood (1996), Multidimensional flux form semi-Lagrangian transport schemes, *Mon. Weather Rev.*, *124*, 2046-2070.

Lin, S. J., and R. B. Rood (1997), An explicit flux-form semi-Lagrangian shallow water model on the sphere, *Q. J. R. Meteorol. Soc.*, *123*, 2477-2498.

Lyapustin, A. (2002), Radiative transfer code SHARM-3-D for radiance simulations over a non-Lambertian nonhomogeneous surface: Intercomparison study, *Appl. Opt.*, *41*, 5607-5615.

Lyapustin, A. (2003), Interpolation and Profile Correction (IPC) method for shortwave radiative transfer in spectral intervals of gaseous absorption, *J. Atmos. Sci.*, *60*, 865-871.

Lyapustin, A. I., and Y. J. Kaufman (2001), Role of adjacency effect in the remote sensing of aerosol, *J. Geophys. Res.*, *106*(D11), 11,909-11,916.

Lyapustin, A., and Y. Knyazikhin (2001), Green's function method in the radiative transfer problem. I: Homogeneous non-Lambertian surface, *Appl. Opt.*, *40*, 3495-3501.

Lyapustin, A., and Y. Knyazikhin (2002), Green's function method in the radiative transfer problem. II: Spatially heterogeneous anisotropic surface, *Appl. Opt.*, *41*, 5600-5606.

Martin, R. B., *et al.* (2002), An improved retrieval of tropospheric nitrogen dioxide from GOME, *J. Geophys. Res.*, *107*, 4437.

McFarlane, N. A. (1987), The effects of orographically excited gravity wave drag on the general circulation of the lower stratosphere and troposphere, *J. Atmos. Sci.*, *44*, 1775-1800.

Newman, P. A., *et al.* (2002), An overview of the SOLVE/THESEO 2000 campaign, *J. Geophys. Res., 107*(D20), 8259, doi:10.1029/2001JD001303.

Numrich, R. W., and J. K. Reid (1998), Co-Array Fortran for parallel programming, *ACM Fortran Forum*, *17*(2), 1-31.

Randall, D., M. Khairoutdinov, A. Arakawa, and W. Grabowski (2003), Breaking the cloud parameterization deadlock, *Bull. Amer. Meteorol. Soc.*, *84*, 1547-1564.

Reichle, R. H., and R. D. Koster (2003), Assessing the impact of horizontal error correlations in background fields on soil moisture estimation, *J. Hydromet., 4*(6), 1229-1242.

Reichle, R. H., R. D. Koster, J. Dong, and A. A. Berg (in press, 2004), Global soil moisture from satellite observations, land surface models, and ground data: Implications for data assimilation, *J. Hydromet*.

Rex, M., *et al.* (1998), In-situ measurements of stratospheric ozone depletion rates in the Arctic winter 1991/1992: A Lagrangian approach, *J. Geophys. Res.*, *103*, 5843–5853.

Rex, M., *et al.* (2002), Chemical depletion of Arctic ozone in winter 1999/2000, *J. Geophys. Res., 107*(D20), 8276, doi:10.1029/2001JD000533.

Salawitch, R. J., *et al.* (1993), Chemical loss of ozone in the Arctic polar vortex in the winter of 1991-1992, *Science*, *261*, 1146–1149.

Whaler, K. A., and M. E. Purucker (2003), Martian magnetization-preliminary models, *The Leading Edge*, *22*(8), 763-765.

Yelick, K., *et al.* (1998), Titanium: A high-performance Java dialect, in *Concurrency: Practice and Experience*, Vol. 10, 825-836.

Zeng, X., M. Shaikh, Y. Dai, R. E. Dickinson, and R. Myneni (2002), Coupling of the Common Land model to the NCAR Community Climate model, *J. Climate, 15*, 1832-1854.

Peer-Reviewed Publications

Adegoke, J. O., R. A. Pielke Sr., J. Eastman, R. Mahmood, and K. G. Hubbard (2003), Impact of irrigation on midsummer surface fluxes and temperature under dry synoptic conditions: A regional atmospheric model study of the U.S. High Plains, *Mon. Wea. Rev.*, *131*, 556-564.

Ahmad, Z., P. K. Bhartia, and N. Krotkov (2004), Spectral properties of backscattered UV radiation in cloudy atmospheres, *J. Geophys. Res., 109,* D01201, 1201-1213, doi:10.1029/2003JD003395.

Ahn, C., J. R. Ziemke, S. Chandra, and P. K. Bhartia (2003), Derivation of tropospheric column ozone from EPTOMS/GOES co-located data sets using the Cloud Slicing Technique, *J. Atmos. Solar Terr. Phys., 65*(10), 1127-1137.

Ajtic, J., B. J. Connor, C. E. Randall, B. N. Lawrence, G. E. Bodeker, J. E. Rosenfield, and D. N. Heuff (2003), Antarctic air over New Zealand following vortex breakdown in 1998, *Annales Geophysicae*, *21*, 2175-2183.

Amalvict, M., N. Debeglia, and J. Hinderer (2003), The absolute gravity measurements performed by Sakuma in France, revisited 20 years later, *Gravity and Geoid 2002, 3rd meeting of the Int. Geoid Gravity Comm.*, edited by I. Tziavos, 76-83.

Amitai, E., J. A. Nystuen, L. Liao, R. Meneghini, and E. Morin (in press, 2004), Uniting space, ground and underwater measurements for improved estimates of rain rate, in *IEEE Geoscience and Remote Sensing Letters*, Vol. 1, No. 2, 35-38.

Amitai, E., J. A. Nystuen, and L. Liao (2004), Listening to the rain, summary of a paper presented at the American Meteorological Society (AMS) 2003 Radar Conference, *Bull. Amer. Meteor. Soc., 15*, January.

Anyamba, A., C. O. Justice, C. J. Compton, and R. Mahoney (2003), Seasonal to interannual variability of vegetation and fires at SAFARI 2000 sites inferred from AVHRR time series data, *J. Geophys. Res. Atmos.,* 108(D13), 8507.

Anyamba, A., C. J. Tucker, R. A. Huete, and B. K. Boken (in press, 2004), Drought monitoring using coarse-resolution polar-orbiting satellite data, in *Agricultural Drought: Global Monitoring and Prediction*, edited by V. K. Boken, A. P. Cracknell, and R. L. Heathcote, Oxford University Press.

Arola A., J. Kaurola, L. Koskinen, A. Tanskanen, T. Tikkanen, P. Taalas, J. R. Herman, N. Krotkov, and V. Fioletov (2003), A new approach to estimating the albedo for snow-covered surfaces in the satellite UV method, *J. Geophys. Res., 108*(D17), 4531-4542, doi:10.1029/2003JD003492.

Bais, A. F., *et al.* (2003), International Photolysis Frequency Measurement and Model Intercomparison (IPMMI): Spectral actinic solar flux measurements and modeling, J. Geophys. Res., 108(D16), 8543-8563, doi:10.1029/2002JD002891.

Balkanski, Y., *et al.* (in press, 2004), The Mt. Cimone, Italy, Free Tropospheric Campaign: Principal characteristics of the gaseous and aerosol composition from European pollution, Mediterranean influences and during African dust events, *Atmos. Chem. Phys*.

Barker, H. W., *et al.* (2003), Assessing 1D Atmospheric Solar Radiative Transfer Models: Interpretation and handling of unresolved clouds, *J. Climate, 16*, 2676-2699.

Bauer, S. E., Y. Balkanski, M. Schulz, D. A. Hauglustaine, and F. Dentener (2004), Global modelling of heterogeneous chemistry on mineral aerosol surfaces: The influence on tropospheric ozone chemistry and comparison to observations, *J. Geophys. Res.*, *109*, D02304, doi:10.1029/2003JD003868.

Bell, T. L., and P. K. Kundu (2003), Comparing satellite rainfall estimates with rain gauge data: Optimal strategies suggested by a Spectral Model, *J. Geophys. Res. 108(*D3), 4121, doi:10.1029/2002JD002641.

Bellouin, N., O. Boucher, D. Tanré, and O. Dubovik (2003), Aerosol absorption over the clear-sky oceans deduced from POLDER-1 and AERONET observations, *J. Geophys. Res.*, *30*(14), 1748, doi:10.1029/2003GL017121.

Bian, H., and C. Zender (2003), Mineral dust and global tropospheric chemistry: Relative roles of photolysis and heterogeneous uptake, *J. Geophys. Res.*, *108*(D21), 4672.

Bleacher, J. E., S. E. H. Sakimoto, J. B. Garvin, and M. Wong (2003), Deflation/erosion rates for the Parva Member, Dorsa Argentea Formation and implications for the south polar region of Mars, *J. Geophys. Res. - Planets, 108*(E7), 5075, doi:10.1029/2001JE001535.

Boone, A., *et al.* (2004), The Rhone-Aggregation Land Surface Scheme Intercomparison Project: An overview, *J. Climate*, *17*, 187-208, 2004.

Bowling, L. C., *et al.* (2003), Simulation of high latitude hydrological processes in the Torne-Kalix basin: PILPS Phase 2e 1: Experiment description and summary intercomparisons, *Global and Planetary Change*, *30*, 1-30.

Boy, J. P., M. Llubes, J. Hinderer, and N. Florsch (2003), A comparison of tidal ocean loading models using superconducting gravimeter data, *J. Geophys. Res.*, *108*(B4), 2193-2210.

Bucsela, E. J., J. S. Morrill, M. Heavner, C. Siefring, S. Berg, D. Hampton, D. Moudry, E. Wescott, and D. Sentman (2003), $N_2(B^3\ \Pi_g)$ and $N_2^+(A^2\Pi_u)$ vibrational distributions observed in sprites, *J. Atmos. Solar-Terr. Phys.*, *65*, 583.

Carn, S. A., A. J. Krueger, G. S. J. Bluth, S. J. Schaefer, N. A. Krotkov, I. M. Watson, and S. Datta (2003), Volcanic eruption detection by the Total Ozone Mapping Spectrometer (TOMS) instruments: A 22-year record of sulfur dioxide and ash emissions, in *Volcanic Degassing, Special Publication of the Geological Society of London on Volcanic Degassing,* edited by C. Oppenheimer, D. M. Pyle, and J. Barclay, 177-202, Geological Society, London, UK.

Chandra, S., J. R. Ziemke, and R. V. Martin (2003), Tropospheric ozone at tropical and middle latitudes derived from TOMS/MLS residual: Comparison with a global model, *J. Geophys. Res., 108*(D9), 4291, doi:10.1029/2002JD002912.

Chou, S. H., E. Nelkin, J. Ardizzone, R. Atlas, and C. L. Shie (2003), Surface turbulent heat and momentum fluxes over global oceans based on the Goddard Satellite Retrievals, Version 2 (GSSTF2), *J. Climate*, *16*, 3256-3273.

Chu, D. A., Y. J. Kaufman, G. Zibordi, J. D. Chern, J-M. Mao, C. Li, and H. B. Holben (2003), Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer (MODIS), *J. Geophys. Res.*, *108*(D21), 4661, doi:10.1029/2002JD003179.

Cohen, W. B., and S. N. Goward (in press, 2004), Landsat's role in ecological applications of remote sensing, *BioScience*.

Cohen, W. B., T. K. Maiersperger, Z. Yang, S. T. Gower, D. P. Turner, W. D. Ritts, M. Berterretche, and S. W. Running (2003), Comparisons of land cover and LAI estimates derived from ETM+ and MODIS for four sites in North America: A quality assessment of 2000/2001 provisional MODIS products, *Remote Sens. Environ., 88*, 233-255.

Cole-Rhodes, A., K. Johnson, J. Le Moigne, and I. Zavorin (2003), Multiresolution registration of remote sensing imagery by optimization of mutual information using a Stocchastic Gradient, *IEEE Trans. Image Processing*, *12*(12), 1495-1511.

Crossley, D., J. Hinderer, M. Llubes, and N. Florsch (2003), The potential of ground gravity measurements to validate GRACE data, *Advances in Geosciences*, *1*, 1-7.

Dong, J., R. K. Kaufmann, R. B. Myneni, C. J. Tucker, P. E. Kauppi, J. Liski, W. Buermann, V. Alexeyev, and M. K. Hughes (2003), Remote sensing estimates of boreal and temperate forest woody biomass: Carbon pools, sources and sinks, *Remote Sens. Environ.*, *84*, 393-410.

Dubovik, O. (in press, 2004), Optimization of numerical inversion in photopolarimetric remote sensing, in *Photopolarimetry in Remote Sensing,* edited by G. Videen, and M. Mishchenko, Kluwer Academic Publishers, Dordrecht.

Duncan, B. N., and I. Bey (in press, 2004), A modeling study of the export pathways of pollution from Europe: Seasonal and interannual variations (1987-1997), *J. Geophys. Res*.

Duncan, B. N., I. Bey, M. Chin, L. J. Mickley, T. D. Fairlie, R. B. Pierce, R. V. Martin, and H. Matsueda (2003), Indonesian wildfires of 1997: Impact on tropospheric chemistry, *J. Geophys. Res.*, *108*, doi:10.1029/2002JD003195.

Eck, T. F., *et al.* (2003), Variability of biomass burning aerosol optical characteristics in southern Africa during the SAFARI 2000 Dry Season Campaign and a comparison of single scattering albedo estimates from radiometric measurements, *J. Geophys. Res.*, *108*(D13), 8477, doi:10.1029/2002JD002321.

Eck, T. F., B. N. Holben, J. S. Reid, N. T. O'Neill, J. S. Schafer, O. Dubovik, A. Smirnov, M. A. Yamasoe, and P. Artaxo (2003), High aerosol optical depth biomass burning events: A comparison of optical properties for different source regions, *J. Geophys. Res.*, *30*(20), 2035, doi:10.1029/2003GL017861.

Eden, S. and R. G. Lawford (2003), Using science to address a growing world-wide water dilemma for the 21st century, in *Water: Science, Management and Policy*, edited by R. G. Lawford, D. Fort, H. Hartmann, and S. Eden, 15-41, American Geophysical Union (AGU), Washington, D. C.

Erfani, A., A. Methot, R. Goodson, S. Belair, K. S. Yeh, J. Cote, and R. Moffet (2003), Synoptic and mesoscale study of a severe convective outbreak with the non-hydrostatic Global Environmental Multiscale (GEM) model, *Meteorol. Atmos. Phys.*, *82*, 31-53.

Errico, R. M. (2003), The workshop on applications of adjoint models in dynamic meteorology, *Bull. Amer. Meteorol. Soc.*, *84*, 795-798.

Errico, R. M., K. Raeder, and M. Ehrendorfer (in press, 2004), Singular vectors for moisture-measuring norms, *Q. J. Roy. Meteorol. Soc., 130*.

Evans, I. N., and A. Koratkar (2004), A complete atlas of recalibrated Hubble Space Telescope faint object spectrograph spectra of active galactic nuclei and quasars. I. Pre-COSTAR Spectra, *Astrophys. J.,* Sup. Series, *150*, 73-164.

Foster, J., C. Sun, J. P. Walker, R. Kelly, A. Chang, J. Dong, and H. Powell (accepted for publication, 2004), Quantifying the uncertainty in passive microwave snow water equivalent observations, *Remote Sens. Environ.*

Garcia, C. A. E, Y. V. B. Sarma, M. M. Mata, and V M.T. Garcia (accepted for publication, 2004), Chlorophyll variability and eddies in the Brazil-Malvinas confluence region, *Deep-Sea Research*.

Gatebe, C. K., M. D. King, S. Platnick, G. T. Arnold, E. F. Vermote, and B. Schmid (2003), Airborne spectral measurements of surface-atmosphere anisotropy for several surfaces and ecosystem over Southern Africa, *J. Geophy. Res., 108*, 8489, doi:10.1029/2002JD002397.

Gatebe, C., M. D. King, A. I. Lyapustin, G. T. Arnold, and J. Redermann (in press, 2004), Airborne spectral measurements of ocean directional reflectance, *J. Atmos. Sci*., CLAMS Special Issue.

Gonzalez-Silvera, A., E. Santamaria-del-Angel, V. M. T. Garcia, C. A. E. Garcia, R. Millán-Nuñez, and F. Muller-Karger (accepted for publication, 2004), Biogeographical regions of the tropical and subtropical Atlantic Ocean off South America: Classification based on pigment (CZCS) and chlorophyll-a (SeaWiFS) variability, *Continental Shelf Research*.

Grab, S., C. K. Gatebe, and A. M. Kinyua (in press, 2004), Ground thermal profiles from Mount Kenya, *Geografiska Annaler*.

Grecu, M., W. S. Olson, and E. N. Anagnostou (in press, 2004), Retrieval of precipitation profiles from multiresolution, multifrequency active and passive microwave observations, *J. Appl. Meteor*.

Griaznov, V., I. Veselovskii, P. Di Girolamo, B. Demoz, and D. N. Whiteman (accepted for publication, 2004), Numerical simulation of light backscattering by spheres with off-center inclusion: Application for lidar case, *Appl.Opt*.

Guild, L. S., W. B. Cohen, and J. B. Kauffman (accepted for publication, 2004), Detection of deforestation and land conversion in Rhondonia, Brazil using change detection techniques, *Int. J. Remote Sens*.

Guild, L. S., J. B. Kauffman, and W. B. Cohen (in press, 2004), Modeling biomass burning emission in primary and regenerating forests and pastures for Jamari, Rondonia, Brazil, *Ecological Applications*.

Haywood, J. M., P. Francis, O. Dubovik, M. Glew, and B. N. Holben (2003), Comparison of aerosol size distributions, radiative properties and optical depths determined by aircraft observations and sunphotometers during SAFARI-2000, *J. Geophys. Res.*, *108*, doi:10.1029/2002JD002250.

Hou, A. Y., S. Q. Zhang, and O. Reale (in press, 2004), Variational continuous assimilation of TMI and SSM/I rain rates: Impact on GEOS-3 hurricane analyses and forecast, *Mon. Weather Rev*.

Hsu, N. C., J. R. Herman, and S. C. Tsay (2003), Radiative impacts from biomass burning in the presence of clouds during boreal spring in southeast Asia, *Geophys. Res. Lett.*, *30*, 1224, doi:10.1029/2002GL016485.

Hsu, N. C., S. C. Tsay, M. D. King, and J. R. Herman (in press, 2004), Aerosol properties over bright-reflecting source regions, *IEEE Trans. Geosci. Remote Sens*.

Jacob, S. D. and L. K. Shay (2003), The role of oceanic mesoscale features on the tropical cyclone induced mixed layer response, *J. Phys. Oceanogr.*, *33*, 649-676.

Jorgensen, D. P., Z. X. Pu, O. Persson, and W. K. Tao (2003), Variations associated with cores and gaps of a Pacific narrow cold frontal rainband, *Mon. Weather Rev., 131*, 2705-2729.

Kelly, R. E. J., and A.T.C. Chang (2003), Development of a passive microwave global snow depth retrieval algorithm for SSM/I and AMSR-E data, *Radio Science*, *38*, doi:10.1029/2002RS002648.

Kelly, R. E. J., A. T. C. Chang, L. Tsang, and J. L. Foster (2003), Development of a prototype AMSR-E global snow area and snow volume algorithm, *IEEE Trans. Geosci. Remote Sens.*, *41*, 230-242.

Kelly, R. E. J., T. J. A. Davie, and P. M. Atkinson (2003), Explaining temporal and spatial variation in soil moisture in a bare field using SAR imagery, *Int. J.Remote Sens., 24*, 3059-3074.

Kinne, S., *et al.* (2003), Monthly averages of aerosol properties: A global comparison among models, satellite data, and AERONET ground data, *J. Geophys. Res.*, *108*(D20), 4634, doi:10.1029/2001JD001253.

Kortz, K. M., E. B. Grosfils, and S. E. H. Sakimoto (2003), Emplacement of long lava flows within a Graben Network in Redunitsa Labyrinthus, Carson Quadrangle, Venus, *Geophys. Res. Lett.*, *30*(17), 1908, doi:10.1029/2003GL017471.

Krueger, S. K., *et al*. (2004), Intercomparison of multi-day simulations of convection during TOGA COARE using several cloud-resolving and single-column models, *Q. J. R. Meteorol. Soc.*, accepted for publication.

Kumar, A., and F. Yang (2003), Comparative influence of snow and SST variability on extratropical climate in northern winter, *J. Climate, 16*, 2248-2261.

Kumar, A., F. Yang, L. Goddard, and S. Schubert (2004), Differing trends in the tropical surface temperatures and precipitation over land and oceans, *J. Climate, 17*, 653-664.

Kundu, P. K., and T. L. Bell (2003), A Stochastic Model of space-time variability of mesoscale rainfall: Statistics of spatial averages, *Water Resour. Res. 39*, 1328, doi:10.1029/2002WR001802.

Kuo, K. S., E. A. Smith, Z. Haddad, E. Im, T. Iguichi, and A. Mugnai (accepted for publication, 2004), Mathematical-physical framework for retrieval of rain DSD properties from dual-frequency Ku/Ka-band satellite radar, *J. Atmos. Sci.*

Lancaster, R. S., J. D. Spinhirne, and K. Manizade (2003), Combined infrared stereo and laser ranging cloud measurements from Shuttle Mission STS-85, *J. Atmos. Ocean. Tech*., *20*, 67-78.

Lary D. J. (in press, 2004), Representativeness uncertainty in chemical data assimilation highlight mixing barriers, *Atmos. Sci. Lett.*

Lary D. J., B. Khattatov, and H. Y. Mussa (2003), Chemical data assimilation: A case study of solar occultation data from the ATLAS 1 mission of the Atmospheric Trace Molecule Spectroscopy Experiment (ATMOS), *J. Geophys. Res. – Atmos.*, *108*(D15), 4456.

Lary, D. J., M. D. Müller, and H. Y. Mussa (2003), Using neural networks to describe tracer correlations, *Atmos. Chem. Phys. Discuss.*, *3*, 5711-5724.

Lau N. C., M. J. Nath, and H. Wang (2004), Model simulations of ENSO-related variability of the coupled atmosphere-ocean system in the East Asian Monsoon region, *East Asian Monsoon*, book series *2*, World Scientific Publishing Company, Singapore.

Lawford, R. G., *et al.* (accepted for publication, 2003), Advancing global and continental scale hydrometeorology: Contributions of the GEWEX Hydrometeorology panel, *Bull. Amer. Meteorol. Soc*.

Lawford, R. G., and D. Fort (2003), Introduction, in *Water: Science, Management and Policy*, edited by R. G. Lawford, D. Fort, H. Hartmann, and S. Eden, 1-12, American Geophysical Union (AGU), Washington, D. C.

Lawford, R. G., J. W. Landwehr, S. Sorooshian, and M. P. L. Whitaker (2003), International hydrologic science programs and global water issues, in *Water: Science, Management and Policy*, edited by R. G. Lawford, D. Fort, H. Hartmann, and S. Eden, 223-245, American Geophysical Union (AGU), Washington, D. C.

Lee, M. I., I. S. Kang, and B. E. Mapes (2003), Impacts of cumulus convection parameterization on the aqua-planet AGCM simulations of tropical intraseasonal oscillation, *J. Meteorol. Soc. Japan*, *81*(5), 963-992.

Le Moigne, J., A. Cole-Rhodes, R. Eastman, K. Johnson, J. Morisette, N. Netanyahu, H. Stone, and I. Zavorin (2003), Earth science imagery registration, in *Proceedings of the 2003 IEEE International Geoscience and Remote Sensing Symposium, IGARSS'03*, Toulouse, France, 21-25 July, IEEE Catalog Number: 03CH37477C, Volume 1, 161-163.

Li, L., G. M. Hemsfield, P. E. Racette, and L. Tian (accepted for publication, 2003), A 94 GHz Cloud Radar System on a NASA ER-2 Aircraft, *J. Atmos. Oceanic Technol*.

Li, S., E. C. Cordero, and D. J. Karoly (2003), Three-dimensional simulations of springtime dissipation of the Antarctic Ozone Hole, *Aust. Met. Mag*., *52*, 1-9.

Lin, S. J., R. Atlas, and K. S. Yeh (2004), Global weather prediction and high-end computing at NASA, *Computing in Science and Engineering*, *6*(1), 29-35.

Liu, A. K., S. Y. Wu, and Y. Zhao (2003), Wavelet analysis of satellite images in ocean applications, in *Frontiers of Remote Sensing Information Processing*, edited by C. H. Chen, 141-162, World Scientific Publishing Co., Singapore.

Liu, H. Y., D. J. Jacob, I. Bey, R. M. Yantosca, B. N. Duncan, and G. W. Sachse (2003), *Transport pathways for Asian combustion outflow over the Pacific: Interannual and seasonal variations*, *J. Geophys. Res., 108*, doi:10.1029/2002JD003102.

Livingston, J. M., *et al.* (2003), Airborne sunphotometer measurements of aerosol optical depth and columnar water vapor during the Puerto Rico Dust Experiment, and comparison with land, aircraft, and satellite measurements, *J. Geophys. Res., 108*, 8588, doi:10.1029/2002JD002520.

Luo, L., *et al.* (2003), Effects of frozen soil on soil temperature, spring infiltration, and runoff: Results from the PILPS 2(d) experiment at Valdai, Russia, *J. Hydromet., 4*(2), 334-351.

Lyapustin, A. (2003), Interpolation and Profile Correction (IPC) method for shortwave radiative transfer in spectral intervals of gaseous absorption, *J. Atmos. Sci.*, *60*, 865-871.

Lyapustin, A., D. Williams, J. Irons, B. Markham, and Y. Wang (in press, 2004), A method for high resolution aerosol retrieval from Landsat data, *J. Atmos. Sci.*, *61*.

Lyons, W. A., J. L. Eastman, T. E. Nelson, D. A. Moon, and C. S. Keen (2003), Available databases in *Air Quality Modeling - Theories, Methodologies, Computational Techniques, and Available Databases and Software. Vol. I – Fundamentals,* edited by P. Zannetti, 409-426, EnviroComp Institute and the Air and Waste Management Association, Pittsburgh, Penn.

Mahanama, S. P. P., and R. D. Koster (2003), Intercomparison of soil moisture memory in two land surface models, *J. Hydromet.*, *4*, 1134-1146.

Mahesh, A. (2004), Improved detection of large particles from infrared spectral observations, *Geophys. Res. Lett.*, *31*, L04110, doi:10.1029/2003GL018768.

Mahesh, A., R. Eager, J. R. Campbell, and J. D. Spinhirne (2003), Observations of blowing snow at the South Pole, *J. Geophys.. Res.*, *108*(D22), 4707, doi:10.1029/2002JD003327.

Mahesh, A., M. A. Gray, S. P. Palm, W. D. Hart, and J. D. Spinhirne (2004), Passive and active detection of clouds: Comparisons between MODIS and GLAS observations, *Geophys. Res. Lett.*, *31*, L04108, doi:10.1029/2003GL018859.

Mallet, M., J. C. Roger, S. Despiau, O. Dubovik, and J. P. Putaud (2003), Microphysical and optical properties of aerosol particles in urban zone during ESCOMPTE, *Atm. Res., 69*, 73-97.

Mallet, M., J. C. Roger, S. Despiau, J. P. Putaud, and O. Dubovik (2004), A method to study the mixing state of Black Carbon, *J. Geophys. Res.*, *109*(D4), D04202, doi:10.1029/2003JD003940.

McArthur, L. J. B., D. H. Halliwell, O. J. Neibergall, N. T. O'Neill, J. R. Slusser, and C. Wehrli (2003), Field comparison of network sunphotometers, *J. Geophys. Res., 108*(D19), 4596, doi:10.1029/2002JD002964.

McGill, M. J., L. Li, W. D. Hart, G. M. Heymsfield, D. L. Hlavka, P. E. Racette, L. Tian, M. A. Vaughan, and D. M. Winker (accepted for publication, 2003), Combined Lidar-radar remote sensing: Initial results from CRYSTAL-FACE and implications for future spaceflight missions, *J. Geophys. Res. Lett*.

Meng, C. J., R. T. Pinker, J. D. Tarpley, and I. Laszlo (2003), A satellite approach to estimate regional land surface energy budget for GCIP/GAPP, *J. Geophys. Res.,108*(D22)*,* 8861.

Mizoguchi, K., S. L. Morey, J. Zavala-Hidalgo, N. Suginohara, S. Häkkinen, and J. J. O'Brien (2003), Decadal variability of the convective activity in the Labrador Sea: Contribution of the preconditioning, *J. Geophy. Res.,*108(C10), 3330, doi:10.1029/2002JC001735.

Morisette, J. E., *et al.* (2003), The use of NASA's Commercial Data Purchase program in support of MODIS land validation, *Remote Sens. Environ., 88*, 100-110.

Morris, G. A., M. R. Schoeberl, J. E. Rosenfield, and C. H. Jackman (2003), The potential impact of subsonic and supersonic aircraft exhaust on water vapor in the lower stratosphere assessed via a trajectory model, *J. Geophys. Res., 108*(D3), doi:10.1029/2002JD002614.

Muller D., I. Mattis, U. Wandinger, A. Ansmann, D. Atthausen, O. Dubovik, E. Sabine, and A. Stohl (2003), Saharan dust over a central European EARLINET-AERONET site: Combined observations with Raman lidar and sunphotometer, *J. Geophys. Res.,108(*D12), 4346, doi:10.1029/2002JD003046.

Narisma, G. T., A. J. Pitman, J. Eastman, I. G. Watterson, R. Pielke Sr., and A. Beltran (2003), The role of biospheric feedbacks in the simulation of the impact of historical land cover change on the Australian January climate, *Geophys. Res. Lett.*, *30*, 2168.

Nijssen, B., *et al.* (2003), Simulation of high latitude hydrological processes in the Torne-Kalix basin: PILPS phase 2e 2: Comparison of model results with observations, *Global and Planetary Change*, *38*, 31-53.

Niyogi, D. S. dutta, R. A. Pielke Sr., K. Alapaty, J. Eastman, T. Holt, U. C. Mohanty, S. Raman, T. K. Roy, and Y. K. Xue (2003), Challenges of land-surface processes in the tropics: Examples over the Indian subcontinent, in *Weather and Climate Modeling*, edited by S. V. Singh, S. Basu, and T. N. Krishnamurti, 132-145, New Age International Limited Publishers, New Delhi.

Numrich, R. W. (2004), Performance metrics based on computational action, *Int. J. High Performance Computing Applications*, Special Issue, *18*(3).

Olsen, M. A., A. R. Douglass, and M. R. Schoeberl (2003), A comparison of Northern and Southern Hemisphere cross-tropopause ozone flux, *Geophys. Res. Lett., 30*(7), 1412, doi:10.1029/2002GL016538.

O'Neill N. T., T. F. Eck, A. Smirnov, B. N. Holben, and S. Thulasiraman (2003), Spectral discrimination of coarse and fine mode optical depth, *J. Geophys. Res.*, *108*(D17), 4559, doi:10.1029/2002JD002975.

O'Neill, N. T., K. B. Strawbridge, S. Thulasiraman, J. Zhang, A. Royer, and J. Freemantle (accepted for publication, 2003), Optical coherency of sunphotometry, sky radiometry and lidar measurements during the early phase of Pacific2001, *Atmospheric Environment*.

Osborne, S. R., J. M. Haywood, P. N. Francis, and O. Dubovik (accepted for publication, 2004), Short-wave radiative effects of biomass burning aerosol during SAFARI2000, *Q. J. R. Meteorol. Soc*.

Pap, J. (2003), The Sun's surface and subsurface, in *Lecture Notes in Physics*, edited by J. P. Rozelot, 128, Volume 599, Springer, Germany.

Pielke, R. A. Sr., D. S. dutta Niyogi, T. N. Chase, and J. L. Eastman (2003), A new perspective on climate change and variability: A focus on India, in *Numerical Modeling of Tropical Mesoscale Processes*, edited by U. C. Mohanty and S. Raman, Proc. Indian National Science Academy, 69A, No. 5, 585-602, New Delhi.

Pielke R.A. Sr., G. Marland, R. A. Betts, T. N. Chase, J. L. Eastman, J. O. Niles, D. S. dutta Niyogi, and S. W. Running (2003), The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases in *Capturing Carbon and Conserving Biodiversity: The Market Approach*, edited by I. R. Swingland, 157-172, Earthscan Publications Ltd., London.

Pu, Z. X.**,** and W. K. Tao (accepted, under revision, 2004), Mesoscale assimilation of TMI rainfall data with 4DVAR: Sensitivity Studies, *J. Meteor. Soc. of Japan.*

Rancić, M., and H. Zhang (in press, 2004), Variable resolution on quasi-uniform grids: Linear advection experiments, *Metor. Atmos. Phys*.

Redemann, J., S. Masonis, B. Schmid, T. Anderson, P. B. Russell, J. M. Livingston, O. Dubovik, and A. Clarke (2003), Clear-column closure studies of aerosols and water vapor aboard the NCAR C-130 in ACE-Asia, *J. Geophys. Res., 108*, 8655, doi:10.1029/2003JD003442.

Reichle, R. H., and R. D. Koster (2003), Assessing the impact of horizontal error correlations in background fields on soil moisture estimation, *Journal of Hydromet., 4*(6), 1229-1242.

Reichle, R. H., R. D. Koster, J. Dong, and A. A. Berg (in press, 2004), Global soil moisture from satellite observations, land surface models, and ground data: Implications for data assimilation, *Journal of Hydromet*.

Reid, J. S., *et al.*, (2003), Analysis of measurements of Saharan dust by airborne and ground-based remote sensing methods during the Puerto Rico Dust Experiment (PRIDE), *J. Geophys. Res*., *108*(D19), 8586, doi:10.1029/2002JD002493.

Reid, J. S., *et al.* (2003), Comparison of size and morphological measurements of coarse mode dust particles from Africa, *J. Geophys. Res.*, *108*(D19), 8593, doi:10.1029/2002JD002485.

Reid, J. S., E. M. Prins, D. L. Westphal, C. C. Schmidt, K. A. Richardson, S. A. Christopher, T. F. Eck, E. A. Reid, and J. P. Hoffman (accepted for publication, 2004), Real-time monitoring of South American smoke particle emissions and transport using a coupled remote sensing/box-model approach, *Geophys. Res. Lett*.

Rodell M., *et al.* (in press, 2004), The global land data assimilation system, *Bull. Amer. Meteorol. Soc*.

Rosat, S., J. Hinderer, and L. Rivera (2003), First observation of $_2S_1$ and study of the splitting of the football mode $_0S_2$ after the June 2001 Peru earthquake of magnitude 8.4, *Geophys. Res. Lett.*, *30(*21), 2111, doi:10.1029/2003GL018304.

Rosat, S., J. Hinderer, D. Crossley, and L. Rivera (2003), The search for the Slichter Mode: Comparison of noise levels of superconducting gravimeters and investigation of a stacking method, *Phys. Earth Planet. Int.*, *140*(1-3), 183-202.

Rosenfield, J. E. (2003), Effects of volcanic eruptions on stratospheric ozone recovery, in *Volcanism and the Earth's Atmosphere,* Geophys. Monogr. Series, 139, edited by A. Robock and C. Oppenheimer, 227-236, AGU, Washington, D. C.

Russell, P. B., J. M. Livingston, O. Dubovik, S. A. Ramirez, J. Wang, J. Redemann, B. Schmid, M. Box, and B. N. Holben (accepted for publication, 2003), Sunlight transmission through desert dust and marine aerosols: Diffuse light corrections to sunphotometry and pyrheliometry, *J. Geophys. Res.*

Sakimoto, S. E. H. (in press, 2004), Volcanoes on Mars: The global view, in *Volcanic Worlds: Volcanism in the Solar System*, edited by R. Lopes and T. K. P. Gregg, Praxis Press, New York.

Sassen, K., W. P. Arnott, D. O'C. Starr, G. G. Mace, Z. Wang, and M. R. Poellot (2003), Midlatitude cirrus clouds derived from hurricane Nora: A case study with implications for ice crystal nucleation and shape, *J. Atmos. Sci., 60*, 873-891.

Sassen, K., Z. Wang, C. Platt, and J. Comstock (2003), Parameterization of infrared absorption in midlatitude cirrus clouds, *J. Atmos. Sci., 60*, 428-433.

Sato, M., J. Hansen, D. Koch, A. Lacis, R. Ruedy, O. Dubovik, B. N. Holben, M. Chin, and T. Novakov (2003), Global atmospheric black carbon inferred from AERONET, *Proc. Natl. Acad. Sci. USA*, *100*(11), 6319-6324.

Schlosser, C. A., and D. M. Mocko (2003), The impact of snow conditions in spring dynamical seasonal predictions, *J. Geophys. Res., 108*(D16), doi:10.1029/2002JD003113.

Schmid B., *et al.* (2003), Column closure studies of lower tropospheric aerosol and water vapor during ACE-Asia using airborne sunphotometer, airborne in-situ and ship-based lidar measurements, *J. Geophys. Res., 108*, 8656, doi:10.1029/2002JD003361.

Seneviratne, S. I., P. Viterbo, D. Lüthi, and C. Schär (in press, 2004), Inferring changes in terrestrial water storage using ERA-40 reanalysis data: The Mississippi River basin, *J. Climate*.

Shay, L. K., and S. D. Jacob (accepted for publication, 2003), Relationship between oceanic energy fluxes and surface winds during tropical cyclone passage, in *Atmosphere-Ocean Interactions, Volume II Special Issue of Advances in Fluid Mechanics*, edited by Wil Perry, WIT Press, Billerica, Mass.

Shie, C. L., W. K. Tao, J. Simpson, and C. H. Sui (2003), Quasi-equilibrium states in the tropics simulated by a cloud-resolving model. Part 1: Specific features and budget analyses, *J. Climate*, *16*, 817-833.

Shige, S., Y. N. Takayabu, W. K. Tao, and D. Johnson (2004), Spectral retrieved of latent heating profiles from TRMM PR data. Part I: Algorithm development with a cloud resolving model, *J. Appl. Meteorol.,* accepted for publication.

Siniuk, A., O. Torres, and O. Dubovik (2003), Combined use of satellite and surface observations to infer the imaginary part of refractive index of Saharan dust, *J. Geophys. Res. Lett.*, *30*, doi:10.1029/2002GL016189.

Siskind, D. E., S. D. Eckermann, J. P. McCormack, M. J. Alexander, and J. T. Bacmeister (2003), Hemispheric differences in the temperature of the summertime stratosphere and mesosphere, *J. Geophys. Res*., *108*(D2), 4051, doi:10.1029/2002JD002095.

Smirnov A., B. N. Holben, O. Dubovik, R. Frouin, T. F. Eck, and I. Slutsker (2003), Maritime component in aerosol optical models derived from AERONET (Aerosol Robotic Network) data, *J. Geophys. Res., 108*(D1), 4033, doi:10.1029/2002JD002701.

Smirnov, A., B. N. Holben, T. F. Eck, O. Dubovik, and I. Slutsker (2003), Effect of wind speed on columnar aerosol optical properties at Midway Island, *J. Geophys. Res.*, *108*(D24), 4802, doi:10.1029/2003JD003879.

Smirnov, A., B. N. Holben, T. F. Eck, O. Dubovik, and I. Slutsker (2003), Effect of wind speed on columnar aerosol optical properties in the Pacific Ocean, *J. Geophys. Res.*, *108*(D24), 4802, doi:10.1029/2003JD003879.

Sprigg, W., and Pap, J. (in press, 2004), Solar variability and its effect on the Earth's atmosphere and climate, *AGU Monograph*, edited by J. M. Pap, P. Fox, C. Froelich, H. S. Hudson, J. Kuhn, J. McCormack, G. North, W. Sprigg, and S. T. Wu.

Strahan, S. E., and A. R. Douglass (accepted for publication, 2004), Evaluating the credibility of transport processes in simulations of ozone recovery using the Global Modeling Initiative 3-D model, *J. Geophys. Res*.

Sun. C., J. P. Walker, and P. R. Houser (in press, 2004), A methodology for snow data assimilation in a land surface model, *J. Geophys. Res. - Atmos*.

Tao, W. K., *et al.* (2003), Microphysics, radiation and surface processes in a non-hydrostatic model, *Meteorol. Atmos. Phys.*, *82*, 97-137.

Tao, W. K., *et al.* (2003), Microphysics, radiation and surface processes in the Goddard Cumulus Ensemble (GCE) model, *Meteorol. Atmos. Phys., 82*, 97-137.

Tao, W. K., *et al.* (2003), Regional-Scale Modeling in NASA Goddard Space Flight Center, *Research Signpost*, *37*(661/2), 1-52.

Tao, W. K., C. L. Shie, D. Johnson, R. Johnson, S. Braun, J. Simpson, and P. E. Ciesielski (2003), Convective systems over South China Sea: Cloud-resolving model simulations, *J. Atmos. Sci.*, *60*, 2929-2956.

Tao, W. K., D. Johnson, C. L. Shie, and J. Simpson (in press, 2004), Atmospheric energy budget and large-scale precipitation efficiency of convective systems during TOGA COARE, GATE, SCSMEX, and ARM: Cloud-resolving model simulations, *J. Atmos. Sci.*

Tao, W. K., Y. Wang, J. Qian, C. L. Shie, K. M. Lau, and R. Kakar (2003), Mesoscale convective systems during SCSMEX: Simulations with a regional climate model and a cloud-resolving model, in *Weather and Climate Modeling,* edited by S. V. Singh, S. Basu, and T. N. Krishnamurti, 75-92, New Age International Publishers, New Delhi, India.

Triggs, J. M., *et al.* (in press, 2004), Free-air CO_2 enrichment effects on the energy balance and evapotranspiration of sorghum, *Agricultural and Forest Meteorology*.

Turato, B., O. Reale, and F. Siccardi (in press, 2004), Large- and regional-scale water vapor sources of the October 2000 Piedmont flood, *J. Hydromet*.

Turner, D. P., W. Ritts, W. B. Cohen, S. T. Gower, M. Zhao, S. W. Running, S. Urbanski, A. Dunn, and J. W. Munger (2003), Scaling Gross Primary Production (GPP) over boreal and deciduous forest landscapes in support of MODIS GPP product validation, *Remote Sens. Environ., 88*, 256-270.

Veselovskii, I., A. Kolgotin, V. Griaznov, D. Müller, K. Franke, D. N. Whiteman (2004), Inversion of multiwavelength Raman lidar data for retrieval of bimodal aerosol size distribution, *Appl. Opt., 43*, 1180-1195.

Waliser, D. E., *et al.* (2003), AGCM simulations of intraseasonal variability associated with the Asian Summer Monsoon, *Clim. Dyn.*, *21*, 423-446.

Walker, J. P., P. R. Houser, and R. H. Reichle (2003), New remote sensing technologies require advances in hydrologic data assimilation, EOS Trans. AGU, Vol. 84, No. 49, 545-551, 9 December.

Wang, J. J. (in press, 2004), Evolution and structure of the mesoscale convection and its environment: A case study during the early onset of south east Asian Summer Monsoon, *Mon. Weather Rev.*

Wang, J. S., J. A. Logan, M. B. McElroy, B. N. Duncan, I. A. Megretskaia, and R. M. Yantosca (in press, 2004), *A 3-D model analysis of the slowdown and interannual variability in the methane growth rate from 1988 to 1997, Global Biogeochem. Cycles*.

Wang, Z., K. Sassen, D. Whiteman, and B. Demoz (2004), Studying altocumulus plus virga with ground-based active and passive remote sensors, *J. Appl. Meteorol., 43*, 449-460.

Weaver, C. J., J. Joiner, and P. Ginoux (2003), Mineral aerosol contamination of TOVS temperature and moisture retrievals, *J. Geophys. Res.*, *108*(D8), AAC 5-1, doi:10.1029/2002JD002571.

Wen, G., R. F. Cahalan, and B. N. Holben (2003), Limitations of ground-based solar irradiance estimates due to atmospheric variations, *J. Geophys. Res.*, *108*(D14), 4400, doi:10.1029/2003JD003431.

Wenig, M., S. Kuhl, S. Beirle, E. Bucsela, B. Jahne, U. Platt, J. Gleason, and T. Wagner (in press, 2004), Retrieval and analysis of stratospheric NO2 from GOME, *J. Geophys. Res*.

Whaler, K. A., and M. E. Purucker (2003), Martian magnetization-preliminary models, *The Leading Edge*, *22*(8), 763-765.

Wu, L, and S. Braun (accepted for publication, 2003), Effects of convective asymmetries on hurricane intensity: A numerical study, *J. Atmos. Sci*.

Wu, L, and B. Wang (in press, 2004), Assessing impacts of climate change on tropical cyclone tracks, *J. Climate*.

Wu, Y., B. Brashers, P. L. Finkelstein, and J. E. Pleim (2003), A multiplayer biochemical dry deposition model, I. Model Formulation, *J. Geophys. Res.*, *108*(D1), doi:10.1029/2002JD002293.

Wu, Y., B. Brashers, P. L. Finkelstein, and J. E. Pleim (2003), A multiplayer biochemical dry deposition model, II. Model evaluation, *J. Geophys. Res.*, *108*, doi:10.1029/2002JD002306.

Yang, F., A. Kumar, M. E. Schlesinger, and W. Wang (2003), Intensity of hydrological cycles in warmer climates, *J. Climate, 16*, 2419-2423.

Yu, H., R. E. Dickinson, M. Chin, Y. J. Kaufman, M. Zhou, L. Zhou, Y. Tian, O. Dubovik, and B. N. Holben (2004), Direct radiative effect of aerosols as determined from a combination of MODIS retrievals and GOCART simulations, *J. Geophys. Res.*, *109*(D3), D03206, doi:10.1029/2003JD003914.

Zavorin, I., and J. Le Moigne (accepted for publication, 2004), On the use of wavelets for image registration, *IEEE Trans. Image Proc.*

Zhan, X., Y. Xue, and G. J. Collatz (2003), An analytical approach for estimating CO_2 and heat fluxes over the Amazonian region, *Ecological Modelling, 162*, 97-117.

Zhao, T. X. P., O. Dubovik, A. Smirnov, B. N. Holben, J. Sapper, D. Tanré, C. Pietras, K. J. Voss, and R. Frouin (2003), Regional evaluation of an Advanced Very High Resolution Radiometer (AVHRR) two-channel aerosol retrieval algorithm, *J. Geophys. Res.*, *109*(D2), D02302, doi:10.1029/2003JD003817.

Zhao, T. X. P., I. Laszlo, O. Dubovik, B. N. Holben, J. Sapper, D. Tanré, and. C. Pietras (2003), A study of the effect of non-spherical dust particles on the AVHRR aerosol optical thickness retrievals, *J. Geophys. Res. Lett.*, *30*(6), doi:10.1029/ 2002GL016379.

Zhao, Y., and A. K. Liu (2003), Applications of sea ice motion and deformation derived from satellite data, in *Proceedings of SPIE 5155 Ocean Remote Sensing and Imaging II*, edited by R. J. Frouin, G. D. Gilbert, and D. Pan, 238-248, SPIE, Bellingham, Wash.

Ziemke, J. R., and S. Chandra (2003), A Madden-Julian Oscillation in tropospheric ozone, *Geophys. Res. Lett., 30*(23), 2182, doi:10.1029/2003GL018523.

Ziemke, J. R., and S. Chandra (2003), La Niña and El Niño-induced variabilities of ozone in the tropical lower atmosphere during 1970-2001, *Geophys. Res. Lett., 30*(3), 1142, doi:10.1029/2002GL016387.

Ziemke J. R., S. Chandra, and P. K. Bhartia (2003), Upper tropospheric ozone derived from the Cloud Slicing technique: Implications for large-scale convection, *J. Geophys. Res., 108*(D13), 4390, doi:10.1029/2002JD002919.

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Other Publications

Arsenault, K. R., P. R. Houser, and D. A. Matthews (accepted for publication, 2003), Incorporating the Land Data Assimilation System into water resource management and decision support systems, *Earth Observing Magazine – ESE Application Division Special Issue*.

Boivin, S., H. A. Margolis, and J. C. Weber (accepted for publication, 2004), Variation in coppice-shoot growth among provenances of *Calycophyllum spruceanum* Benth. in the Peruvian Amazon Basin, *Forest Ecology and Management*.

Garcia C. A. E., M. M. Mata, F. Kurtz, L. Dalla Rosa, and M. M. Muelbert (2003), The activities of the group of high latitude oceanography during the Brazilian Antartic Program Operation 21 from November 2002 to January 2003, technical report, Conselho Nacional de Desenvolvimento Científico e Tecnológico, Ministério de Ciência e Tecnologia, Brazil.

Garcia C. A. E., M. M. Mata, F. Kurtz, L. Dalla Rosa, M. M. Muelbert, and V. M. T. Garcia (2003), The activities of the Group of High Latitude Oceanography during the oceanographic cruise in the Straits of Bransfield and Gerlache -Brazilian Antartic Program Operation 22, technical report/Secretaria da Comissão Interministerial para os Recursos do Mar (SECIRM), Brazil.

Gu, G., and R. F. Adler (2003), Seasonal rainfall variability within the West African Monsoon System, *CLIVAR Exchanges, Newsletter of the Climate Variability and Predictability Programme (CLIVAR)*, World Climate Research Programme (WCRP), *8*(2/3), 11-15.

Kelly, R. E. J., A. T. C, Chang, J. L. Foster, and D. K. Hall (in press, 2004), Using remote sensing and spatial models to monitor snow depth and snow water equivalent, in *Spatial Modelling of the Terrestrial Environment*, edited by R. E. J. Kelly, N. A. Drake and S. Barr, John Wiley and Sons Ltd.

Kelly, R. E. J., N. A. Drake, and S. L. Barr (in press, 2004), Spatial modelling of the terrestrial environment: Outlook, in *Spatial Modelling of the Terrestrial Environment,* edited by R. E. J. Kelly, N. A. Drake and S. Barr, John Wiley and Sons, Ltd.

Kelly, R. E. J., N. A. Drake, and S. L. Barr (in press, 2004), Spatial modelling of the terrestrial environment: The coupling of remote sensing with spatial models, in *Spatial Modelling of the Terrestrial Environment,* edited by R. E. J. Kelly, N. A. Drake, and S. Barr, John Wiley and Sons, Ltd.

Kim, H. R., L. R. Gaya-Pique, R. R. B. von Frese, P. T. Taylor, and J. W. Kim (2004), CHAMP magnetic anomalies of the Antarctic crust, in *2nd CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies.*

Kim, H. R., R. R. B. von Frese, P. T. Taylor, and J. W. Kim (2003), CHAMP enhances utility of satellite magnetic observations to augment near-surface magnetic survey coverage, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*, edited by C. Reigber, H. Lühr, and P. Schwintzer, 296-301, Springer, Germany.

Kim, J. W., H. R. Kim, R. R. B. von Frese, and C. H. Park (2003), Recovery of lithospheric magnetic component in the satellite magnetometer observations of East Asia, in *4th Ørsted International Science Team (OIST-4) Conference Proceedings,* edited by P. Stauning, *et al.*, 99-106, Copenhagen.

Kim, H. R., R. R. B. von Frese, P. T. Taylor, J. W. Kim, and C. H. Park (2003), Utility of satellite magnetic observations for estimating near-surface magnetic anomalies, in *4th Ørsted International Science Team (OIST-4) Conference Proceedings* edited by P. Stauning, *et al.*, 83-86, Copenhagen.

Koratkar, A., J. Jones, J. Jung, and S. Grosvenor (in press, 2004), Science goal driven automation for NASA Missions: The science goal monitor, in *AAAI Spring Symposium Series on Interaction between Humans and Autonomous Systems over Extended Operation*, edited by J. Gunderson and C. Martin, AAAI Press, Menlo Park, Calif.

Kumar, S. (2004), NASA's top feature story: http://www.gsfc.nasa.gov/top_story/2004/0113landair.html.

Lagerloef, G., C. Koblinsky, W. Large, S. D. Jacob, and D. Stammer (2003), Risk mitigation task #1 Aquarius water cycle sensitivity study, final report submitted to NASA ESSP, 14 August.

Lawford, R. G. (2003), Report of the International GEWEX project office, report, Annual GEWEX SSG Meeting, Marrakech, Morocco, January.

Olson W. S., S. Yang, J. Stout, and M. Grecu (in press, 2004), The Goddard Profiling Algorithm (GPROF): Description and current applications, in *Measuring Precipitation from Space - EURAINSAT and the Future,* edited by V. Levizzani, P. Bauer, and F. J. Turk, Kluwer Acad. Publ.

Seneviratne, S. I., P. Viterbo, D. Lüthi, and C. Schär (2003), Inferring changes in terrestrial water storage using ERA-40 reanalysis data: The Mississippi River basin, ERA-40 Project Report Series, *9*, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, UK.

Shay, L. K., S. D. Jacob, T. M. Cook, M. M. McGauley, and C. Zhang (2003), Aircraft based oceanic observations during the Eastern Pacific Investigation of Climate (EPIC), technical report, RSMAS, University of Miami, Miami, Fla.

Taylor, P. T., *et al.* (2004), Effect of varying crustal thickness on CHAMP geopotential data, in *2nd CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*.

Taylor, P. T., J. J. Frawley, H. R. Kim, R. R. B. von Frese, and J. W. Kim (2003), Comparing Magsat, Ørsted and CHAMP crustal magnetic anomaly data over the Kursk Magnetic Anomaly, Russia, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*, edited by C. Reigber, H. Luhr and P. Schwintzer, 302-308, Springer, Germany.

Taylor, P. T., H. R. Kim, R. R. B. von Frese, L.V. Potts, and J. J. Frawley (2003), Satellite-Altitude Geopotnetial study of the Kursk magnetic Anomaly (KMA), in 4*th Ørsted International Science Team (OIST-4) Conference Proceedings,* edited by P. Stauning, H. Lühr, P. Ultré-Guérard, J. LaBrecque, M. Purucker, F. Primdahl, J. Jørgensen, F. Christiansen, P. Høeg, and K. Lauritsen, 95-98, Copenhagen.

Vintzileos, A., M. Rienecker, M. Suarez, S. Miller, P. Pegion, and J. Bacmeister, (2003) Simulation of the El Niño – Southern Oscillation phenomenon with NASA's Seasonal-to-Interannual Prediction Project Coupled General Circulation Model, *CLIVAR – Exchanges*, *28*, 25-27.

von Frese, R. R. B., and H. R. Kim (2003), Satellite magnetic anomalies for lithospheric exploration, in *4th Ørsted International Science Team (OIST-4) Conference Proceedings*, edited by P. Stauning, *et al.*, 115-118, Copenhagen.

von Frese, R. R. B., H. R. Kim, P. T. Taylor, and J. W. Kim (2003), CHAMP, Ørsted, and Magsat Magnetic Anomalies of the Antarctic Lithosphere, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*, edited by C. Reigber, H. Lühr, P. Schwintzer, 309-314, Springer, Germany.

von Frese, R. R. B, L. V. Potts, H. R. Kim, C. K. Shum, P. T. Taylor, J. W. Kim, and S-C. Han (2003), CHAMP gravity anomalies over Antarctica, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*, edited by C. Reigber, H. Lühr, P. Schwintzer, 180-185, Springer, Germany.

von Frese, H. R., Kim, P. T. Taylor, and M. A. Asgharzadeh (2004), Reliability of CHAMP Anomaly Continuations, in *2nd CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies*.

Ziemke, J. R. (2003), Tropospheric data from the United States, 55-58, in *Sounding the Troposphere from Space: A New Era for Atmospheric Chemistry*, edited by P. Borrell, P. M. Borrell, J. P. Burrows, and U. Platt, 446, Springer-Verlag, Germany.

Ziemke, J. R. (2003), Tropospheric data from the United States, 300-302, in *Towards Cleaner Air for Europe - Science, Tools and Applications*, edited by P. M. Midgley, and M. Reuther, 321, Margraf, Germany.

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Conference Presentations and Publications

Ajtic, J., B. J. Connor, B. N. Lawrence, G. E. Bodeker, K. W. Hoppel, J. E. Rosenfield, and D. N. Heuff (2003), Dilution of the Antarctic Ozone Hole into Southern Midlatitudes (1998-2000), poster presented at AGU Fall Meeting, San Francisco, Calif., 8- 12 December.

Amalvict, M., M. N. Bouin, J. Hinderer, and B. Luck (2003), Absolute gravity and GPS measurements as constraints on the post-glacial rebound and present-day ice melting in the French sub-Antarctic Territories, paper presented at 9th Int. Symp. on Antarctic Earth Sciences, International Center for Earth Tides (ICET), Potsdam, Germany, September.

Amalvict, M., J. Hinderer, S. Rosat, Y. Rogister, G. Ferhat, and P. Gegout (2003), Long term and seasonal gravity changes at the Strasbourg station (France) and their relation to crustal deformation, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June - 11 July.

Amitai, E., L. Liao, D. Wolff, D. Marks, and D. Silberstein (2003), Challenges and proposed solutions for validation of spaceborne rain rate estimates, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Amitai, E., L. Liao, X. Llort, and R. Meneghini (2004), Accuracy verification of space and ground-based radar estimates of rain rate, paper presented at Sixth International Symposium on Hydrological Applications of Weather Radar, Melbourne, Australia, 2-4 February.

Amitai, E., J. Nystuen and L. Liao (2003), Uniting space, ground and underwater measurements for better estimation of rain rates, *Proceedings of the 31st International Conference on Radar Meteorology*, 6-12 August, Seattle, Wash., 761-764.

Anyamba, A. (2003), Satellite remote sensing of eco-climatic conditions associated with RVF outbreaks, paper presented at International Consultative Meeting on the Rift Valley Fever in Africa and the Middle East, International Research Institute for Climate Prediction (IRI), World Organization for Animal Health (OiE), Union InterAfrican Bureau for Animal Resources (AU/IBAR), Red Sea Livestock Trade Commission (RSLTC),U.S. Agency for International Development (USAID), Nairobi, Kenya, 2-4 April.

Anyamba, A. (2003), Satellite remote sensing of eco-climatic conditions associated with RVF outbreaks, paper presented at Climate Modeling Workshop for Seasonal Forecasts, Drought Monitoring Center, Nairobi (DMC-N), Nairobi, Kenya, 7-11 April.

Anyamba, A., and C. J. Tucker (2003), 23 years of Sahelian vegetation dynamics from NOAA-AVHRR, paper presented at UNEP/FAO/UNCCED Workshop: Changes in the Sahel, United Nations Environment Programme (UNEP), Nairobi, Kenya, 14-16 October.

Anyamba, A., C. O. Justice, and C. T. Tucker (2003), Global to regional agricultural monitoring using satellite data, paper presented at Joint NASA/USDA Workshop on Agricultural Decision Support Systems, Denver, Col., 4-5 March.

Arsenault, K., *et al.* (2003), An evaluation of the NOAH Land Surface Model implemented in the Global Land Data Assimilation System, paper presented at American Meteorological Society (AMS) 17th Conference on Hydrology, Long Beach, Calif., 11 February.

Bacmeister, J. T. (2003), Rain re-evaporation and the creation of double ITCZs, paper presented at National Center for Atmospheric Research (NCAR) Atmospheric Model Working Group Meeting, Boulder Col., 6 March.

Bacmeister, J. T. (2003), Influence of rain re-evaporation on tropical pacific precipitation patterns, invited paper presented at Geophysical Fluid Dynamics Laboratory (GFDL) Atmospheric Model Development Team Meeting, Princeton New Jersey, 8 April.

Bacmeister, J. T. (2003), Sensitivity of tropical rainfall to re-evaporation, paper presented at Convection Parameterization Workshop, Geophysical Dynamics Laboratory, Princeton, New Jersey, 26 May.

Bacmeister, J. T. (2003), Sub-seasonal variability in the NSIPP AGCM**,** paper presented at NASA/NOAA MJO Sub-seasonal Predicatibility Workshop, College Park, Md., 4 June.

Bacmeister, J. T. (2003), Prognostic cloud simulations in the NSIPP/GMAO AGCM, paper presented at Tropical Cloud CPT Workshop, National Center for Atmospheric Research (NCAR), Boulder Col., 20 November.

Barnes, W., X. Xiong, B. W. Guenther, and V. Salomonson (2003), Development, characterization and performance of the EOS MODIS sensors, paper presented at International Society for Optical Engineering (SPIE) Annual Meeting, San Diego, Calif., 3-8 August.

Bell, T. L., and P. K. Kundu (2003), Estimates of random error in satellite rainfall averages, abstract presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Bell, T. L., and P. K. Kundu (2003), Generating error maps for TRMM gridded monthly rainfall, poster presented at NASA Precipitation Missions Science Team Meeting, Greenbelt, Md., 27-30 October.

Berkoff, T. A., E. J. Welton, J. R. Campbell, V. S. Scott, and J. D. Spinhirne (2003), Investigation of overlap correction techniques for application in the Micro-Pulse Lidar Network (MPLNET), paper presented at 2003 Institute of Electrical and Electronics Engineers, Incorporated (IEEE) International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July.

Berkoff, T. A., E. J. Welton, J. R. Campbell, and J. D. Spinhirne (2003), The Micro-Pulse Lidar NETwork (MPLNET), Frontiers in Optics, paper presented at 87th Optical Society of America (OSA) Annual Meeting, Tucson, Ariz., 5-9 October.

Bian, H., and C. Zender, C. (2003), Global distributions of ammonium aerosol simulated in a global 3-D chemistry-transport model, paper presented at American Association for Aerosol Research 2003 Annual Conference, Anaheim, Calif., October.

Braun, S. A., M. T. Montgomery, and Z. Pu (2003), Asymmetric eyewall vertical motion in a high-resolution simulation of Hurricane Bonnie (1998), paper presented at 10th Conference on Mesoscale Processes, Portland, Oreg., 22-27 June.

Bucsela, E., E. Celarier, J. Gleason, M. Wenig, P. Veefkind, and R. Martin, (2003), Operational algorithm for OMI NO_2 vertical column densities: Investigations with GOME and simulated OMI data, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Carpenter, K. G., *et al.* (2003), The Fizeau Interferometer Testbed for Stellar Imager, paper presented at IAU Symposium 219, Sydney, Australia, July.

Carpenter, K. G., *et al.* (2004), The Stellar Imager (SI) Mission Concept, in *International Society for Optical Engineering (SPIE) Proceedings*, 4854, 2002.

Cede, A., G. Labow, M. Kowalewski, N. Krotkov, and O. Dubovik (2003), Deriving aerosol parameters from absolute UV sky radiance measurements using a Brewer double spectrometer in Ultraviolet Ground- and Space-based measurements, Models, and Effects III, in *Proceedings,* edited by J. R. Slusser, J.R. Herman, and W. Gao, Vol. 5156, 323-329, International Society for Optical Engineering (SPIE), San Diego, Calif.

Chaikovsky, A., A. Bril, V. Barun, O. Dubovik, B. Holben, P. Goloub, and P. Sobolewski (2003), Methodology to retrieve atmospheric aerosol parameters by combining multi-wavelength lidar and sun sky-scanning radiometer data, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Chandra, S., J. R. Ziemke, and X. Tie (2003), Elevated ozone in the troposphere over the Atlantic and Pacific Oceans in the Northern Hemisphere, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Chang, A. T. C., R. E. J. Kelly, J. L. Foster, and D. K. Hall (2003), Global SWE monitoring using AMSR-E Data, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Chang, A. T. C., R. E. J. Kelly, J. L. Foster, and D. K. Hall (2003), The testing of AMSR-E snow depth and snow water equivalent estimates in the Northern Hemisphere, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Chang, Y., et al. (2003), Extreme and sub-seasonal precipitation in the western United States associated with the Madden-Julian Oscillation, paper presented at the National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Chase, Z. A. J., and S. E. H. Sakimoto (2003), Thermal modeling of permafrost melt by overlying lava flows with applications to flow-associated outflow channel volumes in the Cerberus Plains, Mars, abstract #1905 presented at 34th Lunar and Planetary Science Conference, NASA, Houston, Tex., 17-21 March.

Chekalyuk, A. M. (2004), Laser fluorescence analysis of phytoplankton: Beyond chlorophyll concentration, Code 970 Seminar, NASA GSFC, Greenbelt, Md., 26 February.

Chekalyuk, A. M., F. E. Hoge, R. N. Swift, and J. K. Yungel (2003), Advanced oceanic biomonitoring: Pump-and-probe Lidar and phytoplankton pigment analyzer, paper presented at Oceanology International Americas, The Oceanography Society, New Orleans, La., 4-6 June.

Chekalyuk, A. M., F. E. Hoge, R. N. Swift, and J. K. Yungel (2003), New technological developments for ocean lidar biomonitoring, paper presented at Remote Sensing and Space Technology, International Society for Optical Engineering (SPIE) Annual Meeting, San Diego, Calif., 3-8 August.

Chekalyuk, A. M., F. E. Hoge, R. N. Swift, and J. K. Yungel (2003), New technological developments for ocean LIDAR biomonitoring, *Ocean Remote Sensing and Imaging*, 22-29, Vol. 5155, The International Society for Optical Engineering (SPIE).

Chin M., P. Ginoux, O. Dubovik, B. N. Holben, Y. J. Kaufman, A. Chu, T. Anderson, and P. Quinn (2003), Aerosol sources, absorption, and intercontinental transport: Synergies among models, remote sensing, and atmospheric measurements, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Chou, S., E. Nelkin, J. Ardizzone, R. Atlas, and C. L. Shie (2003), Version 2 Goddard Satellite-Based Surface Turbulent Fluxes (GSSTF2), paper presented at 12th Conference on Interaction of the Sea and Atmosphere, American Meteorological Society (AMS), Long Beach, Calif., 9-13 February.

Crossley, D., J. Hinderer, and J. P. Boy (2003), Time variation of the West European gravity field, 1997-2001, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Demoz, B., K. Evans, P. D. Girolamo, Z. Wang, D. Whiteman, G. Schwemmer, B. Gentry, D. Miller, and S. Palm (2003), Lidar measurements of wind, moisture and boundary layer evolution in a dryline during IHOP-2002, paper presented at 12th Conference on Interaction of the Sea and Atmosphere, American Meteorological Society (AMS), Long Beach, Calif., 9-13 February.

Demoz, B., K. Evans, D. Whiteman, P. Di Girolamo, G. Schwemmer, B. Gentry, D. Miller, D. O'C. Starr, and Z. Wang (2003), Moisture, wind, and boundary layer evolution during a dryline in IHOP-2002: May 22, 2002, paper presented at Sixth International Symposium on Tropospheric Profiling, Leipzig, Germany, 14-20 September.

Derimian, Y., A. Karnieli1, Y. J. Kaufman, O. Dudovik, M. O. Andreae, W. Maenhaut, and B. N. Holben (2003), Transportation, optical and chemical properties of atmospheric aerosol over the Negev Desert, paper presented at 2nd Workshop on Mineral Dust, National Center for Scientific Research (CNRS), Paris, France, 10-12 September.

Dubovik, O. (2003), Inversion of spectral aerosol optical thickness and sky radiance to derive aerosol optical and microphysical properties from AERONET, paper presented at Inversion Dept of Meteorology, University of Maryland College Park, Greenbelt, Md., 20 February.

Dubovik, O. (2003), Ground-based aerosol remote sensing by inversion of spectral optical thickness and sky radiance, invited lecture presentation to NATO Advanced Study Institute on Photopolarimetry in Remote Sensing, Yalta, Ukraine, 20 September - 3 October.

Dubovik, O., and E. Vermote (2003), Enhanced retrieval of aerosol properties from the satellite polarimetric measurements of the atmospheric radiation, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Dubovik, O., C. K. Gatebe, A. Sinuyk, E. F. Vermote, M. D. King, and B. N. Holben (2003), Enhanced retrieval of aerosol and surface properties from a combination of up- and down-looking multi-spectral and multi-angular measurements of atmospheric radiation, paper presented to Institute of Electrical and Electronics Engineers, Incorporated (IEEE)/ International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Dubovik, O., B. N. Holben, T. F. Eck, A. Smirnov, T. Lapyonok, A. Siniuk, D. Tanre, P. Goloub, and I. Slutsker (2003), Retrieval of optical properties of desert dust aerosol from AERONET observations, paper presented at 2nd Workshop on Mineral Dust, National Center for Scientific Research (CNRS), Paris, France, 10-12 September.

Duncan, B. and I. Bey (2003), Model study of the export of European pollution: Seasonal and interannual variation (1987-1997), paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Eck, T. F., *et al*. (2003), Aerosol optical properties in Southeast Asia from AERONET observations, paper presented at SKYNET Workshop, Khon Kaen, Thailand, 12 November.

Eck, T. F., B. N. Holben, J. Boonjawat, H. V. Le, J. S. Schafer, J. S. Reid, O. Dubovik, and A. Smirnov (2003), Aerosol optical properties in Southeast Asia from AERONET observations, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Errico, R. M. (2003), A summary of ONR supported predictability work performed by GDS/CGD/NCAR, project report presented at Office of Naval Research (ONR), Arlington, Va., 23 July.

Errico, R. M. (2003), The relevance of Atmospheric Adjoint models, seminar presented at Australian Bureau of Meteorology Research Centre (BMRC), Melbourne, Australia, 12 November.

Errico, R. M. (2003), The changing culture of atmospheric science, seminar presented at Australian Bureau of Meteorology Research Centre (BMRC), Melbourne, Australia, 14 November.

Errico, R. M. (2003), A review of some literature on Ensemble Kalman Filters, invited paper presented at the Workshop on Ensemble Kalman Filters in Oceanic and Atmospheric Data Assimilation, Melbourne, Australia, 18-20 November.

Errico, R. M. (2003), The basics of atmospheric data assimilation, invited paper presented at the Short Course on Atmospheric Data Assimilation of Satellite Observations, American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 8-12 December.

Errico, R. M. (2004), A review of some literature on Ensemble Kalman Filters, seminar presented at Naval Research Laboratory (NRL), Monterey, Calif., 25 February.

Errico, R. M. (2004), The basics of atmospheric data assimilation, invited paper presented at Naval Research Laboratory (NRL), Monterey, Calif., 24 February.

Errico, R. M., and S. Polavarapu (2003), The remaining importance of considering atmospheric dynamical balance, paper presented at The Roger Daley Symposium, McGill University, Montreal, Canada, 1 October.

Feng, H., M. Dowell, J. W. Campbell, and T. S. Moore (2004), The effect of the statistics of optically-active constituents on model-based artificial neural network inversions of ocean color, paper presented at American Society of Limnology and Oceanography (ASLO)/ and The Oceanography Society (TOS) Ocean Research Conference, Honolulu, Hawaii, 14-20 February.

Florsch, N., Llubes, M., Longuevergne, L., and J. Hinderer (2003), Contributions of Rhine water table changes to the superconducting gravimeter measurements in Strasbourg (France), paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Foster, J. L., A. T. C. Chang, D. K. Hall, and R. E. J. Kelly (2003), An examination of South American snow cover extent and snow mass from 1979-2002 using passive microwave satellite data, in *Proceedings of Seventh International Conference on Southern Hemisphere Meteorology and Oceanography,* Wellington, New Zealand.

Froehlick, C., and J. M. Pap (2003), Solar energy flux study: From the interior to the outer layer, paper presented at SCOSTEP ISCS 2003 Symposium, Tayranska Lomnica, Slovakia, June.

Garcia, C. A., and V. M. T Garcia (2003), Ocean color algorithms in the Southwestern Atlantic and Southern Ocean, poster presented at Ocean Color Research Team Meeting, NASA, Miami, Fla., 15-17 April.

Garcia C. A. E, and M. M. Mata (2003), Hidrography and water masses in the Strait of Bransfield during January 2003 - Operantar XXI, abstract and paper presented at XI Seminar on Antarctic Research, Instituto de Geociências, Universidade de São Paulo, Brazil, 15-17 October.

Garcia C. A. E., F. P. de Lima, G. L. Bertoldi, and V. M. T. Garcia (2003), Preliminar validation of chlorophyll-a concentration estimated by SeaWiFS in the Southwestern Atlantic Ocean, abstract and poster presented at XI Seminar on Antarctic Research, Instituto de Geociências, Universidade de São Paulo, Brazil, 15-17 October.

Garcia C. A. E., R. B de Souza, G. Bertoldi, E. Fonseca, and M. M. Mata (2003), Structure and propagation of a Brazilian warm ring in the surface subantarctic waters during the Proantar XXII, abstract and poster presented at XI Seminar on Antarctic Research, Instituto de Geociências, Universidade de São Paulo, Brazil, 15-17 October.

Garvin, J. B., S. E. H. Sakimoto, and J. J. Frawley (2003), Craters on Mars: Global geometric properties from gridded MOLA topography, abstract #3277 in *Sixth International Conference on Mars*, California Institute of Technology, Pasadena, Calif.

Gassó, S. (2003), Passive remote sensing of aerosol mass concentration: Comparisons with in-situ measurements in heavily polluted and dusty environments, paper presented at Gordon Research Conference on Solar Radiation & Climate, Colby-Sawyer College, New London, New Hampshire, 13-18 July.

Gegout, P., H. Legros, and J. Hinderer (2003), 3-D aspherical Earth's model and 3-D atmospheric loading for the new gravity missions, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Gegout, P., H. Legros, and J. Hinderer (2003), 3-D aspherical Earth's model and 3-D atmospheric loading for the new gravity missions, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June - 11 July.

Golynsky, A., *et al.* (2004), ADMAP – A Digital Magnetic Anomaly Map of the Antarctic, paper presented at 9th International Symposium on Antarctic Earth Sciences, Potsdam, Germany.

Gottschalck, J., P. Houser, M. Rodell, U. Jambor, J. Meng, and K. Arsenault (2004), Impact of satellite derived leaf area index on land surface simulation as part of the Global Land Data Assimilation System (GLDAS), paper presented at GEST/JCET Joint Science Symposium, Greenbelt, Md., 22 January.

Grecu, M., and W. S. Olson (2003), Use of polarimetric radar observations in the evaluation of a TRMM combined radar-radiometer algorithm for estimation of precipitation profiles, paper presented at 31st International Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 5-11 August.

Grecu, M., and W. S. Olson (2004), Latent heating retrieval from TRMM observations using a simplified thermodynamic model, paper presented at 26th Conference on Hurricanes and Tropical Meteorology, American Meteorological Society (AMS), Miami, Fla., 2-6 May.

Griaznov, V., I. Veselovskii, P. Di Girolamo, B. Demoz, and D. N. Whiteman (2004), Analysis of scattering properties of eccentric spheres in application to lidar measurements, paper presented at International Laser Radar Conference 22, Coordination Group on Laser Atmospheric Studies, Matera, Italy, 12-16 July.

Guenther, B., X. Xiong, W. L. Barnes, and R. E. Murphy (2003), A calibration algorithm design and analysis for VIIRS Thermal Emissive Bands based on the EOS MODIS Approach, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Guenther, B., X. Xiong, E. Waluschka, W. L. Barnes, and V. V. Salomonson (2003), Results from on-orbit measurements and modeling studies for the MODIS Solar Diffuser Attenuation Screen, paper presented at the ISPRS Gulfport Calibration Workshop, Gulfport, Miss., 2-4 December.

Guenther, B., X. Xiong, and F. DeLuccia (2003), NPOESS VIIRS radiometric uncertainty in thermal emissive bands due to temperature uncertainty for the sensor optics, paper presented at Europtic, International Society for Optical Engineering (SPIE), Barcelona, Spain, 8-12 September.

Gupta, M. L. (2003), Global receptors of regional emissions, Code 916 Seminar, NASA GSFC, Greenbelt, Md., 3 April.

Gupta, M. L., A. R. Douglass, and S. R. Kawa (2003), Meteorological dependence of atmospheric transport of trace gases, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Gupta, M. L., A. R. Douglass, and S. R. Kawa (2003), Intercontinental transport of regionally emitted radon, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice France, 7-11 April.

Hayashi, H., I. Stajner, S. Pawson, and A. M. Thompson (2003), Studies of tropospheric ozone in the DAO ozone assimilation system, paper presented at Aura Science Team Meeting, NASA, Lanham-Seabrook, Md., 20 March.

Hayashi, H., I. Stajner, N. Winslow, D. B. A. Jones, S. Pawson, and A. M. Thompson (2003), Estimating the tropical tropospheric ozone distribution by the assimilation of satellite data, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Hayashi, H., I. Stajner, D. B. A. Jones, S. Pawson, and A. M. Thompson (2004), Tropical Tropospheric Ozone Distribution Produced in the GMAO Ozone Assimilation System, paper presented at GEST/JCET Joint Science Symposium, Greenbelt, Md., 22 January.

Hayne, G., D. Hancock, H. Feng, and D. Vandemark (2003), Attemped ocean surface skewness estimation from Topex wave refitting, paper presented at Jason-1 Science Working Team Meeting, NASA/CNES, Arles, France, 18-21 November.

Haywood, J. M., *et al*. (2003), The direct radiative forcing due to tropospheric aerosols: Validation of surface-based and satellite retrievals and global modeling studies using aircraft data, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April 2003.

Hellmer, H. H., M. Schroder, M. P. Schodlok, and C. A. E. Garcia (2003), Variability of bottom water characteristics and export in the northwestern Weddell Sea, paper and abstract presented at International Union of Geophysics and Geodesy, Sapporo, Japan, 30 June – 11 July.

Herman, J., N. Krotkov, D. Larko, V. Fioletov, Z. Ahmad, and A. Vasilkov (2003), An expanded UV irradiance database from TOMS including the effects of ozone, clouds, and aerosol attenuation, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Heymsfield, G. M., L. Li, L. Tian, M. McGill, and Z. Wang (2003), Thunderstorm generated cirrus observed from X-band and W-band airborne radar during CRYSTAL-FACE, paper presented at 31st Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12 August.

Hinderer, J. (2003), Scientific achievements from time-varying gravity observations using a global network of superconducting gravimeters (The Global Geodynamics Project), paper presented at Goddard Earth and Technology Center, University of Maryland Baltimore County, Greenbelt, Md., November.

Hinderer, J. (2003), Validation of CHAMP and GRACE temporal gravity variations with superconducting gravimeter ground observations, paper presented at NASA Goddard Space Flight Center, Greenbelt, Md., November.

Hinderer, J. (2004), Results from time-varying gravity observations using a global network of superconducting gravimeters (The Global Geodynamics Project), paper presented at Saint Louis University, Saint Louis, Mo., February.

Hinderer, J., and Crossley, D. (2003), Scientific achievements from the first period (1997-2003) of the Global Geodynamics Project using a worldwide network of superconducting gravimeters, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Hinderer, J., D. Crossley, J. Neumeyer, C. Reigber, and J. P. Boy (2004), The Earth's variable gravity field: How to validate satellite data (CHAMP, GRACE) with ground measurements using superconducting gravimeters from the Global Geodynamics Project (GGP), paper presented at Joint GEST/JCET Symposium, NASA Goddard Space Flight Center, Greenbelt, Md., 22 January.

Hinderer, J., J. Neumeyer, C. Reigber, and D. Crossley (2003), Validation of CHAMP and GRACE temporal gravity variations with superconducting gravimeter measurements from the GGP (Global Geodynamics Project) network, paper presented at GRACE Science Team Meeting, Austin, Tex., October.

Holben, B. N., T. F. Eck, O. Dubovik, A. Smirnov, P. Goloub, R. Singh, and R. T. Pinker (2003), AERONET: New aerosol products, data access, and reanalysis of field data for mixtures of fine and coarse mode aerosols, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Hsu, N. C. (2003), Inferring properties of windblown Asian dust over source regions from SeaWiFS, paper presented at Workshop on Future Satellite Remote Sensing Techniques, Paris, France, September.

Hsu, N. C., and J. R. Herman (2004), Regional studies of radiative forcing due to tropospheric aerosols using multisatellite measurements, paper presented at TOMS Science Team Meeting, Boulder, Col., April.

Hsu, N. C., J. Herman, and S. Seftor (2003), Application of the TOMS aerosol products in estimating climate forcing due to aerosols, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Hsu, N. C., S. C. Tsay, and J. R. Herman, Satellite monitoring of Asian dust from TOMS and SeaWiFS, paper presented at APEX Meeting, Osaka, Japan, July.

Hsu, N. C., S. C. Tsay, and B. Holben (2003), Retrieval of aerosol properties over arid and semi-arid regions from SeaWiFS and comprisons with the ground based measurements, paper presented at ACE-Asia Data Workshop, Xian, China, August.

Isaacmann, A., G. Toller, W. Barnes, B. Guenther, and X. Xiong (2003), MODIS level 1B calibration and data products, paper presented at International Society for Optical Engineering (SPIE) Annual Meeting, San Diego, Calif., 3-8 August.

Jacob, S. D, and C. J. Koblinsky (2003), Upper ocean mixing and sea surface salinity, paper presented at Aquarius/ SAC-D First Science Team Meeting, Mar del Plata, Argentina, 18-20 March.

Jacob, S. D., and C. J. Koblinsky (2003), Sea surface salinity and E-P fluxes, invited paper presented at National Oceanic and Atmospheric Administration (NOAA) Environmental Modeling Center, Camp Springs, Md., June.

Jacob, S. D, and C. J. Koblinsky (2003), Fresh water fluxes and sea surface salinity, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Jacob, S. D., C. J. Koblinsky, and B. D. Beckley (2003), Ocean surface topography and vertical structure estimates, paper presented at Ocean Surface Topography SWT Meeting, Arles, France, 16-23 November.

Jacob, S. D., C. J. Koblinsky, and G. R. Halliwell (2003), Upper ocean mixing and sea surface salinity, paper presented at Workshop on Layered Models, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, Fla., 10-12 February.

Jacob, S. D., C. J. Koblinsky, L. K. Shay, and G. R. Halliwell (2003), Effects of entrainment closure on the air-sea fluxes during a tropical cyclone passage, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June - 11 July.

Kahn, R., W. H. Li, C. Bruegge, D. Diner, J. Martonchik, B. Gaitley, O. Dubovik, B. N. Holben, and A. Smirnov (2003), Quantitative constraints on aerosol optical properties over dark water from MISR multi-angle imaging, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Kelly, R. E. J., A. T. C. Chang, J. L. Foster, D. K. Hall, B. B. Stankov, and A. J. Gasiewski (2003), Testing AMSR-E snow retrievals with Cold Lands Processes Experiment data, paper presented at AGU Fall Meeting, San Fransisco, Calif., 8-12 December.

Keller, J. W., J. H. Roark, S. E. H. Sakimoto, S. Stockman, and H. V. Frey (2003), 3-Dimensional topographic models for the classroom, abstract #1973 presented at 34th Lunar and Planetary Science Conference, NASA, Houston, Tex., 17-21 March.

Koratkar, A. (2004), Science goal driven automation for NASA missions: The Science Goal Monitor, paper presented at American Association for Artificial Intelligence (AAAI) Spring Symposium Series, Stanford, Calif., March.

Koster, R. D., M. J. Suarez, P. Liu, and U. Jambor (2004), Alternate approaches to land initialization for seasonal precipitation and temperature forecasts, paper presented at Joint Symposium on Global Change and Climate and the 18th Conference on Hydrology, 84th Annual Meeting of the American Meteorological Society (AMS), Seattle, Wash., 11-15 January.

Krainak, M. A., M. A. Stephen, A. J. Martino, R. S. Lancaster, G. R. Allan, and D. Lunt (2003), Tunable solid-etalon filter for the ICESat/GLAS 532 nm channel lidar receiver, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Krotkov, N. A., P. K. Bhartia. J. R. Herman, A. Vasilkov, O. Dubovik (2003), A model study of the aerosol effects on surface UV irradiance based on AERONET aerosol retrievals, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Krotkov, N. A., S. Datta, A. Krueger, S. Carn, D. Flittner, O. Dubovik, and F. Huang (2003), Measuring sulfur dioxide from space: The promise of Ozone Monitoring Instrument (OMI) on EOS-AURA platform, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Krueger, A., N. A. Krotkov, S. Datta, D. Flittner, O. Dubovik, and F. Huang (2003), Measuring sulfur dioxide from space: The promise of ozone monitoring instrument (OMI) on EOS-AURA Platform, paper presented at The Remote Sensing Conference, Quebec, Canada, February.

Kumar, S. V., C. D. Peters-Lidard, and P. Houser (2003), Early adoption of ESMF by the Land Information Systems, paper presented at NASA Earth Science Technology Conference, College Park, Md., 24-26 June.

Kundu, P. K., and T. L. Bell (2003), A Renormalization Group approach to self-similarity and scaling in rainfall statistics, paper presented at Hydrofractals'03 – An International Conference on Fractals in Hydrosciences, Monte Verità, Ascona, Switzerland, 24-29 August.

Kundu, P. K., and T. L. Bell (2003), A comparative study of rainfall variability as seen by the TRMM PR and the TMI, poster presented at the NASA Precipitation Missions Science Team Meeting, Greenbelt, Md., 27-30 October.

Lancaster, R. S., and B. Beecken (2003), The Economical Microbolometer Based Environmental Radiometer Satellites (EMBERSat) for forest fire detection and monitoring, paper presented at International Thermal Detector Workshop, NASA/GSFC, Adelphi, Md., 19-20 June.

Lary, D. J. (2003), Chemical data assimilation & optimized earth observation, invited paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 8 April.

Lau K. M, and H. Wang (2004), The North Pacific as a regulator of summertime climate over North America and the Eurasia, paper presented at Climate Variability and Predictability (CLIVAR) 2004, Baltimore, Md., 21-25 June.

Lau K. M., H. Wang, and F. Yang (2003), Role of extratropical air-sea interaction on predictability of warm season precipitation over North America, paper presented at NSIPP 2003 Science Team Meeting, College Park, Md., 3-4 September.

Lawford, R. G. (2003), National and international climate and water programs: Challenges and opportunities, invited paper presented at University of Texas, Austin, Texas, March.

Lawford, R. G. (2003), Some US research initiatives to improve river basin management and a review of some issues that could affect US/ Europe collaboration, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Lawford, R. G. (2003), US water cycle research in support of improved water management, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Lawford, R. G. (2003), Making science relevant to stakeholders: Experiences from GAPP (GEWEX Americas Prediction Project) in the water sector, paper presented at Mackenzie GEWEX Study (MAGS) Stakeholder Workshop, Edmonton, Alberta, June.

Lawford, R. G. (2003), Solving the world's water problems with integrated water cycle observations and information, paper presented to United Nations Educational, Scientific, and Cultural Organization (UNESCO) Ambassadors, June.

Lawford, R. G. (2003), Update on the IGOS-P Global Water Cycle theme, paper presented at Annual Meeting of the IGOS-Partners, United Nations Educational, Scientific, and Cultural Organization (UNESCO), Paris, France, June.

Lawford, R. G. (2003), Bridging the gap between hydroclimatological research and water resource decision making: Lessons learned from GCIP/ GAPP research, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June - 11 July.

Lawford, R. G. (2003), Introduction to GAPP mountain interests, paper presented at GEWEX America Prediction Project (GAPP) PIs Meeting, Seattle, Wash., 21-24 July.

Lawford, R. G. (2003), Briefing on GAPP water resource activities, paper presented at Water Resources Research Coordinating Committee, September.

Lawford, R. G. (2003), Issues regarding mountain hydrometeorology arising from the July GAPP workshop, paper presented at GEWEX Hydrometeorology Panel Meeting, Lunnenberg, Germany, September.

Lawford, R. G. (2003), Update on the GEWEX Americas Prediction Project (GAPP), paper presented at GEWEX Hydrometeorology Panel Meeting, Lunnenberg, Germany, September.

Lawford, R. G. (2003), Global climate change and transboundary water issues, paper presented at Groundwater Conference, State of California, Los Angeles, Calif., 28-29 October.

Lawford, R. G. (2003), Observational issues for water resources management: The IGOS water cycle theme, paper presented at Space Technologies for Water Resource Management in Africa, Committee on Earth Observation Satellites, Rabat, Morocco, 6-8 October.

Lawford, R. G. (2003), The Integrated Global Observing Strategy (IGOS) global water cycle theme, paper presented at IGOS-Partnership Meeting, Colorado Springs, Col., 20 November.

Lawford, R. G. (2003), An introduction to the Global Energy and Water Cycle Experiment (GEWEX), invited paper presented at Laboratoire de Meteorologie Dynamique du CNRS (ISLP), Paris, France, 17 December.

Lawford, R. G. (2003), Annual report of the International Global Energy and Water Cycle Experiment (GEWEX) Project Office, report prepared for the read-ahead proceedings of the Annual Global Energy and Water Cycle Experiment (GEWEX) SSG Meeting, Marrakech, Morocco, January, 2004.

Lawford, R. G., and S. Eden (2003), US contributions to the coordinated enhanced observing period, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Lawford, R. G., and J. Huang (2003), Overview of the GAPP Program, GEWEX America Prediction Project (GAPP) PIs Meeting, Seattle, Wash., 21-24 July.

Lawford, R. G., and L. Martz (2003), The use of satellite imaging for indicator development, paper presented at 4th Monitoring Tailor Made Conference, Monitoring Tailor Made Secretariat, The Netherlands, September.

Lawford, R. G., M. Manton, L. Martz, and T. Oki (accepted for publication, 2004), The use of satellite imaging for indicator development, *Proceedings of the 4th Monitoring Tailor Made Conference*, Monitoring Tailor Made Secretariat, The Netherlands.

Lee, M. I., I. S. Kang, B. Mapes, and K. Jin (2003), MJO experiments with the Seoul National University Atmospheric General Circulation Model, paper presented at Workshop on Modeling, Simulation and Forecasting of Subseasonal Variability, University of Maryland, Md., 4-5 June.

Lee, M. I., S. Schubert, M. Suarez, R. Koster, M. Rienecker, and D. Adamec (2003), Current subseasonal-to-seasonal prediction system and on-going activities at NASA's Global Modeling and Assimilation Office, paper presented at International Workshop on Monthly-to-Seasonal Climate Prediction, National Taiwan Normal Univ., Taipei, Taiwan 25-27 October.

Li, L., G. M. Heymsfield, M. J. McGill, Z. Wang, P. E. Racette, L. Tian, D. L. Hlavka, and W. D. Hart (2003), Ice cloud study using cloud radars and cloud lidar on Board ER-2, paper presented at CRYSTAL-FACE Science Team Meeting, NASA, Salt Lake City, Utah, 24-28 February.

Li, L., G. M. Heymsfield, P. E. Racette, L. Tian, and S. W. Bidwell (2003), The 9.6 GHz ER-2 Doppler Radar (EDOP) and the 94 GHz Cloud Radar System (CRS), paper presented at Radar Workshop, National Center for Atmospheric Research (NCAR), Boulder, Col., 23-25 April.

Li, L., G. M. Hemsfield, P. E. Racette, and L. Tian (2003), Calibration of a 94 GHz airborne cloud radar using measurements from the ocean surface, paper presented at 31st Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12, August.

Li, S., and S. Pawson (2003), Sensitivity of middle atmospheric analyses to gravity-wave drag in NASA's data assimilation system, paper presented at GCM-Reality Intercomparison Project for Stratospheric Processes and their Role in Climate (GRIPS) Workshop, Washington, D. C., 4-7 March.

Li, X., W. K. Tao, A. Khain, J. Simpson, and D. Johnson (2003), Radar reflectivity simulated by a 2-D spectra bin model: Sensitivity of cloud-aerosol interaction, paper presented at 31st International Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12 August.

Li, X., W. K. Tao, C. L. Shie, J. Simpson, D. Johnson, and A. Khain (2003), Highlights of recent development in Goddard Cumulus Ensemble Model, paper presented at TRMM Science Meeting, NASA Goddard Space Flight Center, Greenbelt, Md., 27-30 October.

Liao, L., R. Meneghini, and T. Iguchi (2003), Evaluation of TRMM PR attenuation by radar mirror image, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Liao, L., R. Meneghini, T. Iguchi, and A. Detwiler (2003), Validation of snow parameters as derived from dual-wavelength airborne radar, in *Proceedings of the 31st International Conference on Radar Meteorology*, 6-12 August, Seattle, Wash., 411-414.

Lin, R. F., D. O'C. Starr, J. Reichardt, and P. J. DeMott (accepted, 2004), Nucleation in synoptically forced cirrostratus, paper to be presented to 14th International Conference on Clouds and Precipitation (ICCP2004), WMO, IAMAS, and MSC/SMC, Bologna, Italy, 18-23 July.

Lin, S. J, J. D. Chern, K. S. Yeh, B. W. Shen, and W. Putman (2003), Near term and longer term development of FV dynamic core, paper presented at 8th Annual Community Climate System Model (CCSM) Workshop, Breckenridge, Col., 24-26 June.

Lyapustin, A. I. (2003), 3-D radiation effects: Aerosol retrieval over land, Aerocenter Seminar, NASA GSFC, Greenbelt, Md., 7 January.

Lyon, R. G., *et al.* (2004), Building the Fizeau Interferometer Testbed, paper presented at Institute of Electrical and Electronics Engineers, Incorporated (IEEE) Proc: Aerospace Conference, Bigsky, Mont., March.

Mahanama, S. P. P., and R. D. Koster (2004), Impact of GCM climate biases on the simulation of soil moisture memory, paper presented at 18th Conference Hydrology at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 13 January.

Mahesh, A., *et al.* (2003), The Antarctic standard atmosphere, paper presented at Seventh Conference on Polar Meteorology, Hyannis, Mass., 12-16 May.

Margolis, H. A. (2004), Overview of 2003 progress in the Fluxnet-Canada Research Network, paper presented in a plenary session at Fluxnet-Canada Annual Meeting, Banff, Alberta, Canada, 27-29 February.

Margolis, H. A., *et al.* (2004), Progress at the Quebec Flux Station, poster presented at 2004 Fluxnet-Canada Annual Meeting, Banff, Alberta, Canada, 27-29 February.

Martel, M. C., H. A. Margolis, C. Coursolle, F. J. Bigras, and F. A. Heinsch (2004), Photosynthetic acclimation at different spatial scales in an eastern Canadian boreal cutover in the late growing season, poster presented at 2004 Fluxnet-Canada Annual Meeting, Banff, Alberta, Canada, 27-29 February.

Maynard, N, and B. Yurchak (2003), Shared knowledge for decision-making on environment and health issues in the Arctic, paper and poster abstracts presented at SEARCH, Open Science Meeting, The Arctic Research Consortium of the United States (ARCUS), Seattle, Wash., 27-30 October.

Maynard, N., and B. Yurchak (2003), Reindeer Mapper: Perspectives for future cooperation between NASA and world reindeer herders, paper presented at World Reindeer Herding - Arctic Vulnerability Studies and Reindeer Mapper - Needs for New Technologies in Knowledge Production in the North Workshop, Association of World Reindeer Herders, Moscow, 4 October.

Meneghini, R., R. Rincon, and L. Liao (2003), On the use of the log-normal particle size distribution to characterize global rain, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Meng, C. J., *et al.* (2003), Global land surface radiation budget and its impact to water and energy cycles, paper presented at American Meteorological Society (AMS) Annual Meeting, Long Beach, Calif., 10-13 February.

Morris, G. A., M. R. Schoeberl, and B. Bojkov (2003), Evaluating Arctic ozone loss during AASE/2 and SOLVE using MATCH, SOLVE II/Vintersol Joint Science Team Meeting, Orlando, Fla., 21-24 October.

Morris, G. A., M. R. Schoeberl, and B. Bojkov (2003), Diagnosing ozone loss during AASE2 with an Alternate to MATCH, *EOS Trans. AGU*, *84*, Spring Meet. Suppl., 527.

Niepold, F., S. Stockman, S. Sakimoto, J. H. Keller, J. H. Roark, and H.V. Frey (2003), Comparing Earth and Mars: Applying UDL to create a middle school science module, *GSA Abstracts with Programs*, *35*(6), 213-219, September.

Ni-Meister, W., J. Walker, P. Houser, and R. Reichle (2004), Soil moisture initialization for climate prediction through data assimilation, paper presented at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Nirala, M., *et al.* (2003), Observation and illumination effects in MODIS land surface temperature, poster presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Norris, P., A. da Silva, and A. Hou (2003), Assimilation of satellite cloud data into the DAO finite volume Data Assimilation System using a parameter estimation method, paper presented at CloudSat/CALIPSO Science Team Meeting, Colorado State University, Broomfield, Col., 3-6 March.

Numrich, R. W. (2003), Introduction to Co-Array Fortran, invited paper presented at IBM SciComp Users Meeting, Minneapolis, Minn., 5-7 August.

Numrich, R. W. (2003), Co-Array Fortran on BlueGene/L, invited paper presented at IBM BlueGene/L Meeting, Reno, Nev., 14-15 October.

Numrich, R. W. (2003), Panel on productivity metrics, invited paper presented at Supercomputing 2003, Phoenix, Ariz., 15-21 November.

Numrich, R. W. (2003), Tutorial on Co-Array Fortran, invited paper presented at Supercomputing 2003, Phoenix, Ariz., 15-21 November.

Numrich, R. W. (2004), Co-Array Fortran, invited paper presented at University of Maryland, College Park, Md., 4 February.

Numrich, R. W. (2004), Workshop on Co-Array Fortran, invited paper presented at Society for Industrial and Applied Mathematics, PP04, San Francisco, Calif. 25-27 February.

Numrich, R. W. (2004), New methods for developing Peta-Scalable codes, invited paper presented at Pittsburgh Supercomputing Center, Pittsburgh, Pa., 3-4 May.

Numrich, R. W., (2004), Workshop on high productivity programming languages, invited paper presented at Defense Advanced Research Projects Agency, Santa Monica, Calif., 18-19 May.

O' Halloran, T. L., J. D. Fuentes, W. K. Tao, C. L. Shie, and M. Garstang (2004), Verifying modeled tropical convective systems during KWAJEX using surface flux and tethered balloon measurements, paper presented at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Olsen, M. A. (2003), Midlatitude STE investigations at Goddard ACDB, paper presented at Upper Troposphere/Lower Stratosphere Strategic Initiative Workshop, Boulder, Col., October.

Olsen, M. A., and A. E. Dessler (2003), The "Tape Recorder" and the Asian Monsoon, paper presented at Aura Science Team Meeting, Greenbelt, Md., March.

Olsen, M. A., M. R. Schoeberl, and A. R. Douglass (2003), Ozone and Mass STE in the Goddard 3-D CTM, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Olson, W. S., M. Grecu, S. Yang, and W. K. Tao (2004), Evaluation and application of satellite-based latent heating profile estimation methods, paper presented at 26th Conference on Hurricanes and Tropical Meteorology, American Meteorological Society (AMS), Miami, Fla., 2-6 May.

Panchenko, M. V., S. M. Sakerin, B. N. Holben, and A. Smirnov (2003), AEROSIBNET – Siberian system for aerosol monitoring as an important element of worldwide network, paper presented at AERONET World Climate Change Conference, Moscow, Russia, 29 September – 3 October.

Pap, J. M. (2003), Variations of solar irradiance: Summary of the two decade long measurements, invited paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, Nice, France, 7-11 April.

Pap, J. M., M. Turmon, K. E. Shelton, L. E. Floyd, and R. Helizon (2003), Magnetic field and long-term solar irradiance variations over solar cycles 21 to 23, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Pegion, P., *et al.* (2003), Analysis of recent atmospheric climate anomalies using the NSIPP-1 AGCM, paper presented at National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Perez, C. L., A. H. Sobel, G. Gu, D. Johnson, C. L. Shie, and W. K. Tao (accepted, 2004), Simulation of tropical precipitation using the Weak Temperature Gradient approximation applied to the Goddard Cumulus Ensemble Model, paper presentation to 26th Conference on Hurricanes and Tropical Meteorology, American Meteorological Society (AMS), Miami, Fla., 3-7 May.

Peters-Lidard, C. D., S. V. Kumar, Y. Tian, J. L. Eastman, and P. R. Houser (2004), Global urban-scale land modeling with the Land Information System, paper presented at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Peters-Lidard, C. D., Y. Wu, M. Tischler, and P. O'Neil (2003), Operational modeling of soil moisture at local and regional scales, paper presented at First Interagency Conference on Research in the Watersheds, ARS, USGS, USFS, BLM, EPA and CUAHSI, Benson, Ariz., 28-30 October.

Polit, A. T., S. E. H. Sakimoto, D. E. Mitchell, and E. B. Grosfils (2003), Geometric properties of possible volcanoes in the South Polar region of Mars, abstract #1514 presented at 34th Lunar and Planetary Science Conference, NASA, Houston, Tex., 17-21 March.

Pu, Z. X. (2003), Application of data assimilation in improving hurricane modeling and forecasts, paper presented at Hurricane Research Division, National Oceanic and Atmospheric Administration (NOAA), Miami, Fla., 14 July.

Pu, Z. X. (2003), Application of data assimilation in improving atmospheric modeling, paper presented at Department of Meteorology, University of Utah, Salt Lake City, Utah, 29 September.

Pu, Z. X. (2003), Assimilation of NASA precipitation data for improving mesoscale forecasts, paper presented at NASA Precipitation Missions Science Team Meeting, College Park, Md., 27-30 October.

Racette, P. E., G. M. Hemsfield, L. Li, L. Tian, and E. Zenker (2003), The cloud radar system, paper presented at 31st Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12 August.

Reichle, R. H., and R. D. Koster (2003), Assessing the impact of horizontal error correlations in background fields on soil moisture estimation with the Ensemble Kalman Filter, paper presented at Workshop on Ensemble Weather Forecasting in the Short to Medium Range, Val-Morin, Quebec, Canada, September.

Reichle, R. H., P. R. Houser, M. Rodell, R. D. Koster (2003), Recent progress in land data assimilation at NASA, invited paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Reichle, R. H., R. D. Koster, and J. Dong (2004), On global soil moisture from satellite observations, land surface models, and ground data, and implications for land data assimilation, paper presented at the 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Reid, J. S., D. L. Westphal, S. A. Christopher, E. M. Prins, C. O. Justice, K. A. Richardson, E. A. Reid, and T. F. Eck (2003), Modeling and mechanisms of intercontinental transport of biomass-burning plumes, paper presented at AGU Fall Meeting, San Francisco, Calif., 8 December.

Roark, J. H., J. H. Keller, F. Niepold, S. Sakimoto, S. Stockman, and H.V. Frey (2003), 3-Dimensional topographic models of geologic features in the classroom, *GSA Abstracts with Programs*, *35*(6), 46-36, September.

Rosat, S., J. Hinderer, and L. Rivera (2003), Stacking with superconducting gravimeters of the GGP (Global Geodynamics Project) network in the quest for the $_2S_1$ and $_1S_1$ modes, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Rosat, S., J. Hinderer, and L. Rivera (2003), Observation of attenuation and splitting after the 2001 M=8.4 Peru earthquake and the possible detection of the Slichter mode from the superconducting gravimeters of the GGP (Global Geodynamics Project), paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Rosenfield, J. E., R. Stolarski, and S. Hollandsworth-Frith (2003), Comparison of 2-D coupled model ozone profile trends with SBUV trends, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Rosenfield, J. E., R. Stolarski, and S. Hollandsworth-Frith (2003), Ozone profile trends: Comparison of SBUV observations with results from a 2-D chemical model, poster presented at Gordon Research Conference on Solar Radiation & Climate, Colby-Sawyer College, New London, New Hampshire, 13-18 July.

Russo, F., D. N. Whiteman, B. Demoz, I. Veselovskii, S. H. Melfi, and R. M. Hoff (2004), Development of Raman lidar techniques to address the indirect aerosol effect: Retrieving the liquid water content of clouds, paper presented at International Laser Radar Conference 22, Coordination Group on Laser Atmospheric Studies, Matera, Italy, 12-16 July.

Sakimoto, S. E. H., T. K. P. Gregg, S. S. Hughes, and J. Chadwick (2003), Re-assessing Plains-style Volcanism on Mars, abstract # 3197 in *Sixth International Conference on Mars*, California Institute of Technology, Pasadena, Calif.

Sakimoto, S. E. H., T. K. P. Gregg, S. S. Hughes, and J. Chadwick, Martian plains volcanism in Syria Planum and Tempe Mareotis as analogs to the Eastern Snake River Plains, Idaho: Similarities and possible petrologic contributions to topography, abstract #1740 presented at 34th Lunar and Planetary Science Conference, NASA, Houston, Tex., 17-21 March.

Sakimoto, S. E. H., S. S. Hughes, T. K. P. Gregg, J. Chadwick, and S. L. Weren (2003), Field constraints on remote sensing shield volcano intrepretations: Quantitative constraints from the Snake River Plains and extensions to Mars, in *GSA Abstracts with Programs*, *35*(6), Paper 107-11, September.

Schneider, E., C. Sun, M. Rienecker, S. Zebiak, A. Rosati, J. Kinter, A. Kaplan, and D. Behringer (2003), Ocean Data Assimilation Consortium for Seasonal-to-Interannual Prediction (ODASI), paper presented at CEDP Consortium, National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Schubert, S., *et al.* (2003), The impact of ENSO on extreme winter weather of the continental United States, paper presented at National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Seneviratne, S. I. (2004), Large-scale estimates of changes in terrestrial water storage using streamflow measurements and ERA-40 atmospheric reanalysis data, paper presented at GMAO Seminar, Code 900.3, NASA/GSFC, 5 February.

Shie, C. L., W. K. Tao, and J. Simpson (2003), Simulated KWAJEX convective systems using a 2-D and 3-D cloud resolving model and their comparisons with radar observations, in *Proceedings of the 31st Conference on Radar Meteorology,* 441-444, American Meteorological Society (AMS).

Shie, C. L., W. K. Tao, and J. Simpson (2003), Simulated SCSMEX & KWAJEX convective systems using a Goddard Cumulus Ensemble (GCE) model, paper presented at Coastal Ocean Assessment and Analysis (COAA) 2003 Annual Meeting, Catholic University of America, Washington, D. C., 25 October.

Shie, C. L., W. K. Tao, J. Simpson (2004), Simulations of TRMM/SCSMEX & KWAJEX convective systems using a Goddard Cumulus Ensemble (GCE) model, poster paper presented at UMBC Joint GEST/JECET Symposium, Greenbelt, Md., 22 January.

Shie, C. L., W. K. Tao, and J. Simpson (accepted, 2004), Various applications on tropical convective systems using a Cloud Resolving Model (CRM), paper presentation to 26th Conference on Hurricanes and Tropical Meteorology, American Meteorological Society (AMS), Miami, Fla., 2-6 May.

Shie, C. L., W. K. Tao, and J. Simpson (accepted, 2004), Various applications on tropical convective systems using a Goddard Cumulus Ensemble (GCE) model, paper to be presented to 14th International Conference on Clouds and Precipitation (ICCP2004), WMO, IAMAS, and MSC/SMC, Bologna, Italy, 18-23 July.

Shie, C. L., W. K. Tao, and J. Simpson (accepted, 2004), Various numerical applications on tropical convective systems using a Cloud Resolving Model (CRM), paper presentation to 3rd International Ocean-Atmosphere Conference (COAA 2004), Beijing, China, 27-30 July.

Shige, S., Y. N. Takayabu, W. K. Tao, D. E. Johnson, and C. L. Shie (2003), Spectral retrieval of latent heating profiles from TRMM PR data: Comparison of look-up tables, paper presented at Joint ICCP, IRC and ICACGP Symposium for International Association of Meteorology and Atmospheric Sciences (IAMAS)/ International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporro, Japan, 30 June - 3 July.

Shige, S., Y. N. Takayabu, W. K. Tao, D. E. Johnson, and C. L. Shie (accepted, 2004), Spectral retrieval of latent heating profiles from TRMM PR data: Comparison of look-up tables, paper presentation to 26th Conference on Hurricanes and Tropical Meteorology, American Meteorological Society (AMS), Miami, Fla., 2-6 May.

Smirnov, A., B. N. Holben, O. Dubovik, T. F. Eck, and I. Slutsker (2003), Maritime aerosol optical model derived from Aerosol Robotic Network data, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Smirnov, A., B. N. Holben, O. Dubovik, T. F. Eck, J. S. Schafer, N. T. O'Neill, I. Slutsker, P. Goloub, and B. Chatenet (2003), Aerosol Robotic Network: Past, present and future, paper presented at Workshop on Global Aerosol Measurements for Climate Studies- Present and Future, National Center for Scientific Research (CNRS), Paris, France, 15-19 September.

Solyar, G., C. Chang, D. Reuter, and G. McCabe (2003), Information extraction and retrieval- based data compression for remotely sensed imagery, paper presented at NASA Hyperspectral Imaging Conference, GSFC, June.

Stankov, B. B., A. J. Gasiewski, B. L. Weber, M. Klein, R. E. J. Kelly, D. Cline, and G. A. Wick (2003), Airborne measurements of snow cover properties during the Cold Land Processes Experiments (CLPX02/03) using the Polarimetric Scanning Radiometer (PSR), paper presented at AGU Fall Meeting, San Fransisco, Calif., 8-12 December.

Starr, D. O'C., B. Demoz, R. F. Lin, and A. Lare (accepted, 2004), Cirrus simulations of CRYSTAL-FACE 23 July 2002 case, paper to be presented to 14th International Conference on Clouds and Precipitation (ICCP2004), WMO, IAMAS, and MSC/SMC, Bologna, Italy, 18-23 July.

Starr, D. O'C., R. F. Lin, A. Lare, B. Demoz, T. Rickenbach, D. Wang, L. Li, G. T. Arnold, Y. Wang (accepted, 2004), Mesoscale simulations of CRYSTAL-FACE 23 July 2002 case, paper to be presented to 14th International Conference on Clouds and Precipitation, WMO, IAMAS, and MSC/SMC, Bologna, Italy, July 18-23, 2004.

Strahan, S. E. (2003), Evaluation of Model Credibility in GMI 3-D simulations of an ozone recovery scenario, paper presented at the Global Modeling Initiative Science Team Meeting, NASA, Seabrook, Md., 15-17 May.

Strahan, S. E. (2003), The Global Modeling Initiative, invited paper presented at NASA Atmospheric Composition Focus Area Review, Washington, D.C., 11 September.

Strahan, S. E., and A. R. Douglass (2003), The development and erosion of the Antarctic vortex in Spring, paper presented at the Process Oriented Validation of Coupled Chemistry-Climate Models Workshop, Institute of Atmospheric Physics of the German Aerospace Center, Garmisch-Partenkirchen, Germany, 18-20 November.

Strahan, S. E. and A. R. Douglass (2003), Tropical isolation in the middle stratosphere, poster presented at the Process Oriented Validation of Coupled Chemistry-Climate Models Workshop, Institute of Atmospheric Physics of the German Aerospace Center, Garmisch-Partenkirchen, Germany, 18-20 November.

Strahan, S. E., and A. R. Douglass (2003), Model temperature diagnostics for gas phase stratospheric chemistry, poster presented at the Process Oriented Validation of Coupled Chemistry-Climate Models Workshop, Institute of Atmospheric Physics of the German Aerospace Center, Garmisch-Partenkirchen, Germany, 18-20 November.

Sun, C., C. Keppenne, and M. Rienecker (2004), Observational impact on seasonal forecast skills using the NSIPP Ocean Data Assimilation System, paper presented at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Sun, C., J. Walker, and P. Houser (2003), Error estimation and assimilation of satellite snow mass observations, paper presented at Roger Daley Memorial Symposium, Montreal, Canada, 29 September - 1 October.

Tao, W. K., R. Atlas, C. L. Shie, A. Hou, S. J. Lin, and D. O'C. Starr (2003), Sensitivity of microphysics and model configuration on precipitation processes, paper presented at Workshop on the Future of Cloud Parameterization, Princeville, Kauai, Hawaii, 7-9 May.

Tao, W. K., A. Khain, S. Simpson, D. Johnson, X. Li, and L. Remer (2003), The impact of aerosols on cloud and precipitation processes: Cloud-resolving model simulations, paper presented at Weather Analysis and Forecasting, Central Weather Bureau, Taipei, Taiwan, ROC, 15-17 September.

Tao, W. K., S. Lang, J. Simpson, R. Meneghini, J. Halverson, R. Johnson, and R. Adler (2003), Vertical profiles of latent heat release over the global tropics using TRMM rainfall products from December 1997 to November 2002, paper presented at International Latent Heat Meeting at EORC/NASDA, Tokyo, Japan, 2 September.

Tao, W. K., X. Li, A. Khain, J. Simpson, D. Johnson, and L. Remer (2003), The impact of aerosols on cloud and precipitation processes: Cloud-resolving model simulations, paper presented at International Association of Meteorology and Atmospheric Sciences (IAMAS)/ International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Tao, W. K., C. L. Shie, J. Simpson, D. O'C. Starr, D. Johnson, and Y. Sud (2003), Precipitation processes developed during ARM (1997), TOGA COARE (1992), GATE (1974), SCSMEX (1998), and KWAJEX (1999): 2-D and 3-D cloud resolving model simulations, paper presented at 13th ARM Program Science Team Meeting, Broomfield, Col., 31 March - 14 April.

Tao, W. K., C. L. Shie, S. Lang, and J. Simpson (2003), Cloud modeling using field project data for the study of precipitation processes, paper presented at International Association of Meteorology and Atmospheric Sciences (IAMAS)/ International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Tao, W. K, X. Zeng, C. L. Shie, D. O'C. Starr, and J. Simpson (2004), The impact of model configuration and large-scale, upper level forcing on CRM-simulated convective systems, paper presented at ARM Science Meeting, Albuquerque, N. Mex., 22-26 March.

Teixeira C. E. P., M. M. Mata, and C. A. E. Garcia (2003), Análise harmônica da temperatura superficial do mar no setor Atlântico do Oceano Austral a partir de imagens AVHRR/NOAA, abstract and poster presented at XI Seminar on Antarctic Research, Instituto de Geociências, Universidade de São Paulo, Brazil, 15-17 October.

Thulasiraman S., N. T. O' Neill, S. L. Gong, J. McConnell, L. Neary, J. Kaminski, A. Lupu, and A. Royer (2004), Evaluation of modeled aerosol properties on a Global Climatological Scale (GCMIII model) and on a Meteorological, Air Quality Scale (GEM-AQ model), paper presented at XIII National Space Science Symposium held at Mahatma Gandhi University, Kottayam, Kerala, India, 17-20 February.

Tian, L., G. M. Hemsfield, and L. Li (2003), Straiform precipitation observed by airborne radar at 94 GHz and 10 GHz, paper presented at 31st Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12 August.

Torres, O., A. Siniuk, P. K. Bhartia, O. Dubovik, and B. Holben (2003), Remote sensing of aerosol absorption using ground-based AERONET and space TOMS observations, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Vandemark, D., M. Bertrand Chapron, H. Feng, and B. Beckley (2003), Evaluating the sea state bias using wave model data, paper presented at Jason-1 Science Working Team Meeting, NASA/CNES, Arles, France, 18-21 November.

Veselovskii, I., A. Kolgotin, D. Müller (2003), Retrieval of bimodal aerosol size distribution with multiwavelength Mie-Raman lidar, paper presented at Sixth International Symposium on Tropospheric Profiling, Leipzig, Germany, 14-20 September.

Veselovskii, I., A. Kolgotin, D. Müller, and D. N. Whiteman (2004), Information content of multiwavelength lidar data on the base of eigenvalues analysis, paper presented at International Laser Radar Conference 22, Coordination Group on Laser Atmospheric Studies, Matera, Italy, 12-16 July.

Vintzileos, A. (2003), Simulation and prediction of the ENSO phenomenon with the NSIPP-1 forecasting system, paper presented at European Geophysical Society (EGS)/ American Geophysical Union (AGU)/ European Union of Geoscience (EUG) Joint Assembly, Nice, France, 7-11 April.

Vintzileos, A. (2003), Prospects for seasonal forecasting of Indian Ocean sector climate variability, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo Japan, 30 June – 11 July.

Vintzileos, A. (2003), The NSIPP-1 forecasting system - Issues concerning tropical SST prediction: Initialization shocks and drifts, paper presented at NSIPP Science Team Meeting, College Park, Md., 3-4 September.

Vintzileos, A. (2003), Simulation and forecast of ENSO with the NSIPP model, paper presented at Seminar at International Research Institute, Columbia University, Palisades, New York, 9 December.

Vintzileos, A., M. Rienecker, M. J. Suarez, S. Schubert, and N. Kurkowski (2003), On Seasonal variations in the initial drift of a coupled model with implications for ENSO forecasting, paper presented at National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Vintzileos, A., M. Rienecker, M. J. Suarez, and S. Schubert (2004), The effect of ocean data assimilation on the Spring Predictability Barrier of ENSO during the 1993-2002 decade, paper presented at 84th American Meteorological Society (AMS) Annual Meeting, Seattle, Wash., 11-15 January.

Vintzileos, A., M. Rienecker, M. J. Suarez, S. Schubert, N. Kurkowski, and J. Jacob (2004), A possible limit for ENSO predictability, paper presented at European Geophysical Union (EGU) 1st Meeting, Nice, France, 24-30 April.

Vintzileos, A., M. Rienecker, M. J. Suarez, S. Schubert, N. Kurkowski, and J. Jacob (2004), A possible limit for ENSO predictability, paper presented at Climate Variability and Predictability (CLIVAR) 2004 Meeting, Baltimore, Md., 21-26 June.

Wang H., and N. C. Lau (2003), Response of South Asian Monsoon climate to global warming in GFDL ensemble climate simulations, paper presented at 14th Symposium on Global Change and Climate Variations, American Meteorological Society (AMS), Long Beach, Calif., 8-13 February.

Wang, H., and K. M. Lau (2003), Maintenance of recurrent teleconnection patterns linking climate variability over the U.S. and Pacific during boreal summer, paper presented at National Oceanic and Atmospheric Administration (NOAA) 28th Annual Climate Diagnostics and Prediction Workshop, Reno, Nev., 20-23 October.

Wang, J. J. (2003), Rainfall characteristics and kinematic structure of a mesoscale convection observed during the onset of South East Asian monsoon, paper presented at 31st Conference on Radar Meteorology, American Meteorological Society (AMS), Seattle, Wash., 6-12 August.

Wang, J. J. (2003), The organization and structure of mesoscale convection during the South China Sea Monsoon Experiment (SCSMEX), paper presented at 10th Conference on Mesoscale Processes, American Meteorological Society (AMS), Portland, Oreg., 22-26 June.

Wang, Z. (2003), Studying altocumulus plus virga with ground-based active and passive remote sensors, paper presented at CloudSat and CALIPSO Science Team Meeting, Broomfield, Col., 3-7 March.

Wang, Z., and K. Sassen (2003), Combined lidar and radar approaches for characterizing clouds, paper presented at CloudSat and CALIPSO Science Team Meeting, Broomfield, Col., 3-7 March.

Wang, Z., K. Sassen, D. Whiteman, and B. Demoz (2003), Studying altocumulus plus virga with ground-based active and passive remote sensors, in *Proceedings of the ARM Science Team Meeting*, 31 March - 4 April, Broomfield, Col.

Wang, Z., D. Whiteman, B. Demoz, and I. Veselovskii (2004), A new way to measure cirrus ice water content by using Ice Raman Scatter with Raman lidar, paper presented at International Laser Radar Conference 22, Coordination Group on Laser Atmospheric Studies, Matera, Italy, 12-16 July.

Weaver, C. J., A. da Silva, P. Ginoux, and M. Chin (2003), Preliminary results from an aerosol assimilation system of MODIS radiances using the GOCART Aerosol Transport Model, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Wen, G. (2003), Phase space reconstruction and predictability from SOLSTICE, paper presented at SORCE Science Meeting, Sonoma, Calif., 4-6 December.

Wen, G., and R. F. Cahalan (2003), Empirical orthogonal function analysis of solar spectral irradiance from SOLSTICE, paper presented at International Union of Geodesy and Geophysics (IUGG) Meeting, Sapporo, Japan, 30 June – 11 July.

Wen, G., and R. F. Cahalan (2003), Time series analysis of solar spectral irradiance from SOLSTICE measurements, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Weren, S. L., and S. E. H.Sakimoto (2003), Martian polar volcanoes: Characteristics, implications for effusive vs. explosive eruptions and differentiation from polar impact craters, *GSA Abstracts with Programs*, *35*(6), Paper 67-3, September.

Whiteman, D. N., B. Demoz, P. DiGirolamo, J. Comer, Z. Wang, R-F. Lin, K. Evans, and I. Veselovskii (2004), NASA/GSFC Scanning Raman Lidar measurements of water vapor and clouds during IHOP, paper presented at International Laser Radar Conference 22, Coordination Group on Laser Atmospheric Studies, Matera, Italy, 12-16 July.

Whiteman, D., B. Demoz, P. Di Girolamo, Z. Wang, K. Evans, and R. F. Lin (2003), NASA/GSFC Scanning Raman Lidar measurements of water vapor and clouds during the International H2O Project (IHOP) field campaign, paper presented at Sixth International Symposium on Tropospheric Profiling, Leipzig, Germany, 14-20 September.

Wu, Y., C. Peters-Lidard, R. Dennis, and P. Finklestein (2003), Soil moisture effects on gaseous exchanges between the atmosphere and the biosphere, paper presented at American Meteorological Society (AMS) Spring Meeting, Long Beach, Calif., 5-6 February.

Xiong, X., J. Esposito, J. Sun, B. Guenther, W. Barnes, and R. Murphy (2003), The impact of solar diffuser screens on the radiometric calibration of remote sensing systems, paper presented at International Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, 21-25 July.

Xiong, X., V. Salomonson, K. Chiang, A. Wu, S. Xiong, N. Chen, W. Barnes, and B. Guenther (in press, 2003), On-orbit characterization of Terra MODIS Thermal Emissive Bands Response versus Scan Angle, in *Proceedings CALCON '03*, edited by P. Huber, Space Dynamics Laboratory, Utah State University, Logan, Utah.

Xiong, X., J. Sun, X. Liu, J. Esposito, W. L. Barnes, and B. Guenther (2003), On-orbit characterization of a solar diffuser's bi-directional reflectance factor using space maneuvers, paper presented at International Society for Optical Engineering (SPIE) Annual Meeting, San Diego, Calif., 3-8 August.

Yang, F. (2003), Intensity of hydrological cycles in warmer climates, invited paper presented at International Young Scientists' Global Change Conference, Trieste, Italy, 16-20 November.

Yang, F. (2003), Intensity of hydrological cycles in warmer climates, poster presented at Gordon Research Conference on Solar Radiation & Climate, Colby-Sawyer College, New London, New Hampshire, 13-18 July.

Zavorin, I., and J. Le Moigne (2003), Application of multi-resolution wavelet pyramids and gradient search based on mutual information to sub-pixel registration of multi-sensor satellite imagery, paper presented at International Society for Optical Engineering (SPIE) 48th Annual Symposium on Imaging Science and Technology, San Diego, Calif., 3-8 August.

Zavorin, I., H. Stone, and J. Le Moigne (2003), Evaluating performance of automatic techniques for sub-pixel registration of remotely sensed imagery, paper presented at International Society for Optical Engineering (SPIE) Electronic Imaging 2003, Image Processing: Algorithms and Systems II Conference, Santa Clara, Calif., 20-24 January.

Zender, C., H. Bian, S. Bortz, and R. Arimoto (2003), The impact of dust emission and deposition on biogeochemical cycyling and ecosystem function, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Zhan, X., W. Gao, X. Pan, and Y. Ma (2003), Monitoring the hydrologic and vegetation dynamics of arid land with satellite remote sensing and mathematical modeling, in *Proceedings of SPIE's 3rd International Asia-Pacific Environmental Remote Sensing Symposium*, edited by X. Pan, W. Gao, M. H. Glantz, and Y. Honda, 4890, 115-127, International Society for Optical Engineering (SPIE), Bellingham, Wash.

Zhan, X., W. Gao, J. Qi, P. Houser, and X. Pan (2003), Remote sensing and modeling the dynamics of soil moisture and vegetative cover of arid and semiarid areas, in *Proceedings of the Ecosystems Dynamics, Agricultural Remote Sensing and Modeling, and Site-Specific Agriculture Conference, SPIE's 48th Annual Meeting: Optical Science and Technology*, edited by W. Gao, and D. R. Shaw, 5153, 51-60, International Society for Optical Engineering (SPIE), Bellingham, Wash.

Zhan, X., P. Houser, and J. Walker (2003), Retrieving soil moisture from HYDROS radar and radiometer observations using Kalman Filter Data Assimilation Algorithm, paper presented at NASA HYDROS Science Team Meeting, Pasadena, Calif., 26 August.

Zhang, X., K. Carpetner, R. G. Lyon, H. Huel, J. Marzouk, and G. Solyar (2003), The Fizeau Interferometer Testbed, paper presented at paper presented at Institute of Electrical and Electronics Engineers, Incorporated (IEEE) Proc: Aerospace Conference, Bigsky, Mont., March.

Zhao, Y., and A. K. Liu (2004), Sea ice motion and deformation derived from satellite data in the Arctic and Okhotsk Sea, in *Proceedings of the 19th International Symposium on Okhotsk Sea and Sea Ice,* Mombetsu, Hokkaido, Japan, 22-26 February.

Ziemke, J. R. (2003), Recent studies of tropospheric ozone from TOMS measurements and photochemical models, paper presented at University of Maryland (College Park) Meteorology Dept., September.

Ziemke, J. R., and S. Chandra (2003), A Madden-Julian Oscillation in tropospheric ozone, paper presented at AGU Fall Meeting, San Francisco, Calif., 8-12 December.

Grant Proposals and Status

(sorted by funding agency)

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Determination of the Effects of Non-Modality on the Data Assimilation and Numerical Weather Prediction Problems	ATM	Errico (GEST)		Funded
Aerosol and chemical instrumentation to maintain the Eureka Arctic observatory	Canadian Foundation for Innovation	Drummond (University of Toronto)	O'Neill (GEST)	Funded
Modelling and aerosol measurement infrastructure for key nodes in the GEM-AQ community	Canadian Foundation for Innovation	McConnel (York University)	O'Neill (GEST)	Funded
Exploring Planetary Topography in the Classroom Using 3-Dimensional Models	DDF	Keller	Frey (GSFC) Roark (SSAI) Sakimoto (GEST) Stockman (SSAI)	Funded
DoD-GEIS utilization of remotely sensed satellite data to monitor and forecast Rift Valley fever and other vector-borne disease outbreaks	DoD	Anyamba (GEST) Tucker (GSFC)		Funded
Development, testing, and monitoring of remotely sensed satellite data to monitor and forecast Rift Valley fever and other vector-borne disease outbreaks—determination of natural vs. unnatural outbreaks using time series satellite data	DoD	Tucker (GSFC)	Anyamba (GEST)	Funded
Peta-Scale Application Development Analysis	DOE	Lucas (ISI; U. of So.Cal.)	Numrich (GEST)	Pending
Using Radar, Lidar, and Radiometer Measurements to Classify Cloud Type and Study Middle-level Cloud Properties	DOE ARM	Z. Wang (GEST)		Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Retrieving Aerosol Properties over Bright-Reflecting Surfaces: An Extension of Current MOD04/MYD04 Products	EOS	Hsu (GEST)		Funded
High Resolution Modeling of Land-Atmosphere Ammonia Exchanges	EPA	Y. Wu (GEST, Co-PI)	Peters-Lidard (GSFC, Co-PI) Schwede (EPA)	Funded
Numerical Investigation of Soil Moisture and Temperature Effects on the Spatial Pattern of Biogenic Emissions	EPA	Y. Wu (GEST, Co-PI)	Peters-Lidard (GSFC, Co-PI) Schwede (EPA)	Funded
Improved Water Demand Forecasting for Water Resources Managers	GEWEX/GAPP/OGP	Matthews (U.S. Bureau of Reclamation)	Houser (GSFC) Arsenault (GEST) Hartzell (U.S. Bureau of Reclamation).	Funded
An Intercomparison of LDAS Evapotranspiration and Soil Moisture Estimates with the Regional Reanalysis Data	GEWEX/GAPP/OGP	Toll (NASA)	Houser (GSFC) Arsenault (GEST) Pinheiro (NRC)	Funded
Airborne Transport Of Aerosols Into The South Atlantic Ocean: Assessment Of Sources, Horizontal Fluxes, Iron Fertilizing Potential And Impact On Climate	IAI/NSF	Gaiero	Gassó (GEST) Chemale Jr. Conceição Bidart	Funded
Coastal Ecosystems of the South American Region (CESAR): An integrated satellite data management and distribution system	Inter-American Institute for Global Change Research (IAI) and NSF	C. Garcia (GEST)		Funded
South Atlantic Climate Change (SACC)	Inter-American Institute for Global Change Research (IAI) and NSF	C. Garcia (GEST)	V. Garcia (GEST)	Funded
Simulation of Shortwave VIIRS Testbed for Aerosol and Land Surface EDRs	IPO	Lyapustin (GEST)	Wang (GEST)	Funded
Variability of ocean properties in the Bransfield and Gerlache Straits	Ministery of Environment and Ministery of Science and Technology, Brasil	C. Garcia (GEST)	V. Garcia (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
SAR Observation of Reindeer Habitats in Northern Russia	NASA		Yurchak (GEST)	Funded
Development of an Internally Consistent, Multi-sensor, Multi-Platform Long-term Series of Global Snow Cover Using Heritage and EOS-Era Data	NASA	Armstrong (University of Colorado)	Chang (NASA) England (University of Michigan) Kelly (GEST)	Funded
Error Estimates for TRMM and GPM Average Rain-Rate Maps	NASA	Bell (GSFC)	Kundu (GEST)	Funded
Remote Sensing of Primary Production in the Southwestern Atlantic Ocean	NASA	C. Garcia (GEST)	V. Garcia (GEST)	Funded
Tropospheric ozone data products derived from TOMS measurements and comparisons with 3-D chemical transport models	NASA	Chandra (GEST)	Ziemke (GEST)	Funded
Assessment of phytoplankton physiology and primary productivity from MODIS Fluorescence products	NASA	Chekalyuk (GEST)	Hoge	Not Funded
A Global Model Analysis of Anthropogenic Aerosol Radiative Forcing Using Data from Terra and Aqua Satellites, Ground-Based Networks, and In-Situ Measurements	NASA	Chin	Remer (GSFC) Kaufman (GSFC) Dubovik (GEST) Colatz	Funded
Orbiting Carbon Observatory (OCO). Funded by NASA's Earth System Science Pathfinder (ESSP) program	NASA	Crisp (JPL)	Pawson (GEST)	Funded
Proposal for Continued Funding of the Stratospheric General Circulation with Chemistry Project	NASA	Douglass (GSFC)	Kawa (GSFC), Stolarski (GSFC), Steenrod (GSFC), Olsen (GEST), Gupta (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Enhanced remote sensing of atmospheric aerosol by multi-sensor AERONET/MISR/MODIS retrieval	NASA	Dubovik (GEST)	Martonchik Kaufman (GSFC) Holben (GSFC)	Funded
Coupling Troposphere and Ionosphere	NASA	Eberstein, (GSFC)	Rančić, JCET/GEST/UMBC	Not Funded
Global Estimates of Evaporation from Variational Assimilation of Multi-Platform Land Surface Temperature into a Dynamic Model of the Surface Energy Balance	NASA	Entekhabi (GSFC)	Margulis (GEST) Reichle (GEST)	Funded
The 6th International Workshop on Adjoint Applications in Dynamic Meteorology	NASA	Errico (GEST)		Funded
Synergistic use of multiple satellite instruments to derive tropospheric ozone in anticipation of improved measurement capabilities from OMI and other data products from EOS-CHEM	NASA	Fishman	Chandra (GEST) Ziemke (GEST)	Funded
Analysis of Seasonal Snow Characteristics in South America from 1979-2003 Using Passive Microwave Data	NASA	Foster (NASA)	Kelly (GEST)	Funded
Optimal land surface temperature estimation and assimilation for global hydrological applications	NASA	French (NRC)	Houser (GSFC) Meng (GEST) Pinheiro (NRC)	Funded
Closure in Model Prediction, In-Situ Measurements and Remote Sensing of Aerosol Mass Concentration	NASA	Gassó (GEST)	Tsay (GSFC)	Funded
Spectral, Angular and Vertical Characterization of Aerosol for Radiative Properties	NASA	Gatebe (GEST)	Dubovik (GEST) Tsay (GSFC)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Variability of aerosols distribution and optical properties simulated by GOCART model using TOMS, aerosol data and AERONET measurements	NASA	Ginoux (GFDL)	Chin Torres (GSFC) Dubovik (GEST)	Funded
Physically-Based Continuous Fields and Land Cover Mapping Algorithm Using MODIS and Multi-Source Data	NASA	Hall (GSFC)	Peddle Huemmrich (JCET) Lyapustin (GEST)	Funded
Assimilated data sets of atmospheric ozone for June and August 1999	NASA	Hayashi (GEST)		Funded
Improved Understanding of TRMM PR Derived Products Using Aircraft Radar Observations	NASA	Heymsfield (GSFC)	Tian, Li (GEST)	Funded
Advanced Resources Evaluation and Networking Area (ARENA)	NASA	Hoban (GEST)	Laughlin (GEST)	Funded
NASA Explorer Schools News	NASA	Hoban (GEST)	Laughlin (GEST) Delaney (GEST)	Funded
Ground-based Aerosol Measurement and Characterization	NASA	Holben (GSFC)	Dubovik (GEST) Eck (GEST) Nelson Smirnov (GEST)	Funded
Optimal Precipitation Estimation for Global Land Surface Application	NASA	Houser (GSFC)	Gottschalck (GEST) Arsenault (GEST) Vicente (GMU) Nirala (NRC)	Not Funded
Chemical Forecasting and Quick-Look CTM Analysis in Support of INTEX-A	NASA	Jacob (Harvard)	Pawson (GEST)	Funded
Quantifying the sources and Transport of Combustion Gases and Aerosols Using MOPITT, MODIS, MISR and Complementary Satellite Observations	NASA	Jacob (Harvard)	Pawson (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
The Use of NASA Land Data Assimilated Products to Improve Flood and Drought Risk Analysis and Forecasting for Water Resources Management in the Columbia River Basin	NASA	K.R. Arsenault (GEST)	Houser (GSFC) Matthews Hartzell Meyer Sharp (U.S. Bureau of Reclamation).	Funded
The Global Aerosol System and its direct and indirect forcing of climate	NASA	Kaufman (GSFC)	Remer (GSFC) Chin Dubovik (GEST) Feingold Koren Martins da-Silva (GSFC) Torres	Funded
Characterizing global snow persistence and its effect on seasonal climate prediction	NASA	Kelly (GEST)	Schlosser (GEST) Sun (GEST) Reichle (GEST)	Not Funded
Assimilation of Satellite Observations of the Land Surface in support of NASA's Seasonal-to-Interannual Prediction Project	NASA	Koster	Reichle (GEST), Rienecker (GSFC), Suarez (GSFC), Walker (GSFC), Houser (GSFC)	Funded
Development of new instrumentation and methodology for measurements of column aerosol absorption in UV-VIS spectral region	NASA	Krotkov (GEST)	Herman (GSFC) Labow (SSAI) Dubovik (GEST) Whiteman (GSFC) Holben (GSFC)	Not Funded
Statistics of AMSR-E Rainfall for Data Validation and Application to NASA-GCM Simulations	NASA	Kundu (GEST)		Not Funded
Study of 3-D Effects in Landsat Atmospheric Correction	NASA	Lyapustin (GEST)	Wang (GEST)	Funded
Analysis and Validation of the Aerosol and Surface Reflectance EDRs over Land for the Visible/Infrared Imaging Radiometer Suite	NASA	Lyapustin (GEST)	Wang (GEST) Privette (GSFC) Holben (GSFC)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Unified Non-Lambertian 3-D Retrieval and Validation of Land Surface Reflectance From MODIS	NASA	Lyapustin (GEST)	Wang (GEST) Descloitres (SSAI) Slutsker (SSAI) Holben (GSFC)	Funded
A community-driven North American disturbance record and processing system for land satellite data	NASA	Masek (GSFC)	Hall (JCET) Wolfe (SSAI) Masuoka (GSFC) Lyapustin (GEST)	Funded
Atmospheric Transport of Trace Gases and Aerosols: Evaluating Models and Observations	NASA	McMillan (UMBC)	Morris (GEST)	Funded
Ground-based UV Sensor	NASA	Morris (GEST)		Equipment loan
The Asian Monsoon and Stratospheric Water Vapor	NASA	Olsen (GEST)		Pending
Long-term Solar Irradiance Variations and their Effect on the Earth's Atmospheric Climate	NASA	Pap (GEST)		Pending
Long-term Solar Irradiance Variations Over Solar Cycles 21 to 23	NASA	Pap (GEST)		Funded
Study of Total Irradiance Variations Measured by ACRIMSAT	NASA	Pap (GEST)		Pending
Variations in Total Solar and Spectral Irradiance Related to Solar Magnetic Activity	NASA	Pap (GEST)		Funded
Global Analysis and Modeling of Ice Clouds in a Sub-synoptic Environment (GAMICSE)	NASA	Pawson (GEST)		Funded
Reanalysis for Stratospheric Trace-gas Studies (ReSTS)	NASA	Pawson (GEST)		Funded
Use of AIRS and MODIS data to define the impact of land-surface conditions on the African easterly jet and the Atlantic hurricane season	NASA	Reale (GEST)	Robert Atlas (GSFC)	Not Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Assimilation of AMSR-E data and application to the initialization of soil moisture reservoirs in a seasonal forecasting system	NASA	Reichle (GEST)	Koster (GSFC), Zhan (GEST) Jambor (GEST) Bacmeister (GEST) Houser (GSFC)	Funded
Global Land Data Assimilation System phase 2: Scientific discovery	NASA	Rodell (GSFC)	Houser (GSFC) Mitchell (NOAA) Gottschalck (GEST) Jambor (GEST) Meng (GEST) Arsenault (GEST) Bosilovich (GSFC) Zhan (GEST)	Not Funded
Ocean Surface Topography and Vertical Structure Variability	NASA	S. Daniel Jacob (GEST)		Pending
The Role of Freshwater Fluxes and Ocean Mixing on Sea Surface Salinity and Upper Ocean Salt Budget	NASA	S. Daniel Jacob (GEST)		Pending
Plains Volcanism and Small Volcanic Edifices on Mars	NASA	Sakimoto (GEST)	Gregg (SUNY Buffalo) Greeley (Arizona State University) Hughes (Idaho State University)	Funded
Atmospheric Transport of Trace Gases and Aerosols: Evaluating Models and Observations	NASA	Schoeberl (GSFC)	Douglass (GSFC) Stolarski (GSFC) Newman (GSFC) Thompson (GSFC) Pawson (GEST) Chin Rosenfield (GEST) Lait Sparling (JCET) Hollandsworth Morris Torres (GSFC) Colarco Olsen (GEST)	Funded
The Interaction Between the Troposphere and Stratosphere: The Impact of Climate Change	NASA	Schoeberl (GSFC)	Pawson (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
An AGCM study of extreme winter weather events over the United States and their links to ENSO	NASA	Schubert (GSFC)	Chang (GEST) Max Suarez (GSFC)	Funded
Ozone assimilation for studies of polar regions	NASA	Stajner (GSFC)	Strahan (GEST)	Funded
Observationally based process evaluation of model transport: Improving atmospheric models and the GMI assessment capability	NASA	Strahan (GEST)	Douglass (GSFC)	Funded
The Global Modeling Initiative at NASA Goddard Space Flight Center	NASA	Strahan (GEST) Clune (GSFC)	Douglass (GSFC)	Funded
Fires as a Disturbance in the Earth-Atmosphere System, a Pilot Study Using MODIS Data and Experimental Algorithms	NASA	Vermote	Dubovik (GEST)	Funded
Better understanding atmospheric water vapor, clouds and precipitation using Terra, Aqua and ground-based measurements	NASA	Wang (GEST)		Pending
Improvement to the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)	NASA	Wang (GEST)	Evans Racette Heymsfield (GSFC) Li	Funded
Spectral Signatures of AEROSOLS from Satellite Data	NASA	Weaver (GEST)		Funded
Raman Lidar for studies of aerosol indirect effect	NASA Radiation Sciences Program (RSP)	Whiteman (GSFC)	Veselovskii (GEST)	Funded
Multi-wavelength Raman Lidar Measurements for Studies of the Aerosol Indirect Effect and AERONET Algorithm Development	NASA	Whiteman (GSFC)	Veselovskii (GEST) Demoz Lin Dubovik (GEST)	Funded
I3RC workshop and 3-D Radiative Transfer	NASA OES	Cahalan (GSFC)	Wen (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
CloudSat Level 2 Combined Radar and Lidar Cloud Scenario Classification Standard Product Development	NASA/JPL	Wang (GEST)		Funded
Science Goal Monitor: Tools for Science Goal Capturing and Onboard Goal Monitoring	NASA's CICT	Jones	Koratkar (GEST)	Funded
Optimal land initialization for the operational NCEP Global Forecast System	NASA-NOAA Joint Center for Satellite Data Assimilation	Mitchell (NOAA)	Meng (GEST)	Funded
North American Monsoon onset and maintenance sensitivity to land and ocean surface conditions	National Oceanic and Atmospheric Administration	Bosilovich	Chern (GEST) Arsenault GEST) Paul R. Houser	Funded
Validation of GLDAS land surface states and forcing within the GAPP region	NOAA	Gottschalck (GEST)	Rodell (GSFC) Houser (GSFC)	Not Funded
The Impact of Approximation of Topography on Surface Hydrology in Seasonal Time-scale Integrations over Western Cordilleras	NOAA	Ranĉić, GEST/UMBC	Gwo, Department of Civil & Environmental Engineering, (UMBC)	Not Funded
Evaluation of upper ocean mixing parameterizations	NOAA	S. Daniel Jacob (GEST)		Funded
Mycosporine amino acid LIDAR (MAAL) technology for remote HAB detection and monitoring	NOAA/Coastal Ocean Program	Chekalyuk (GEST)	Mitchell	Pending
Advanced laser fluorescence (ALF) technology for estuarine and coastal Environmental Biomonitoring	NOAA/Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)	Chekalyuk (GEST)	Moore White Porter	Funded
Characterization and detection of HAB species with laser excitation-emission matrix analysis	NOAA/ECOHAB	Chekalyuk (GEST)	Anderson Kirkpatrick Bailey	Not Funded
The North American Monsoon onset and maintenance sensitivity to land and ocean surface conditions	NOAA/JCSDA	Bosilovich (NASA)	Houser (GSFC) Arsenault (GEST) Chern (GEST)	Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
Assimilation of MODIS and AMSR-E Land Products into the Noah LSM	NOAA/JCSDA	Houser (NASA)	Arsenault (GEST) Zhan (GEST) Cosgrove (SAIC)	Funded
Including Atmospheric Aerosols in the Optical Path Transmittance Model (OPTRAN)	NOAA/NASA	Weaver (GEST)		Funded
Climate Process Team for Tropical Clouds	NSF	Bretherton	Bacmeister (GEST)	Funded
Science on the Semantic Web	NSF	Finin (UMBC)	Hoban (GEST)	Funded
Educating with Virtual Experience (EVE 2003)	NSF	Hoban (GEST)	Laughlin (GEST)	Funded
Development of a Multi-Angle Sky-Viewing DOAS Instrument for Validating Aura's OMI Data Products	NSF	Mount	Janz (GSFC) Bhartia (GSFC) Bucsela (GEST) Hilsenrath (GSFC)	Funded
Research on the Development and Applications of Adjoint Models and Ensemble Techniques	ONR	Errico (GEST)		Funded
Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA)	Radiation Science Program	Tsay Hsu (GEST)		Funded
Measuring Urban Ozone Pollution in Houston, Texas with MICROTOPS to examine the feasibility of using MICROTOPS to observe spatial and temporal gradients in column ozone due to tropospheric ozone pollution	Rice Space Institute Seed Money Program	Morris (GEST)		Funded
Rice University Tropospheric Ozone Pollution Project to investigate tropospheric ozone pollution in Houston, Texas	Shell	Morris (GEST)		Funded

Proposal Title	Funding Agency	PI	Co-I(s)	Status
The Application of NASA EOS MODIS Data to Agricultural Assessment and Forecasting by the USDA Foreign Agricultural Service	USDA and NASA	Justice (UMCP)	Anyamba (GEST) Tucker (GSFC) Doorn (FAS-FAS) Reynolds (FAS-USDA)	Funded

Biographies

Dr. Assaf Anyamba is an assistant research scientist at GEST. He received his undergraduate degree from Kenyatta University, Nairobi, Kenya in geography and economics (1989), and a master's degree in geography from Ohio University, Athens (1992). He received his Ph.D. (1997) in geography, with a focus on remote sensing of land surface patterns of ENSO from Clark University, Worcester, MA. His research interests are in the extraction of interannual climate variability signals from remotely sensed vegetation measurements, drought pattern analysis, applications of remotely sensed data in agricultural monitoring, drought and famine early warning, and the links between climate and disease outbreaks. His current work supports research and development for U.S. Department of Agriculture (USDA)/ Foreign Agricultural Service (FAS) - Production Estimation and Crop Assessment Division (PECAD) and United States Agency for International Development (USAID)/ Famine Early Warning Systems Network (FEWSNET) and Department of Defense (DoD) - Global Emerging Infections System (GEIS) programs.

Ms. Kristi R. Arsenault received a B.S. degree in geography and climatology from Arizona State University in May 1997. While at Arizona State, she interned at the NASA Mars Global Surveyor Tropospheric Emission Spectrometer (TES) Laboratory for two years, working on the interplay between dust storms and the northern polar ice cap of Mars. After graduating, Ms. Arsenault attended The Ohio State University in Columbus, Ohio, where she pursued a master's of science degree in atmospheric sciences on a graduate fellowship. While at Ohio State, she was also a teaching assistant for introductory level meteorology and geography courses, and a research assistant at the Byrd Polar Research Center. Her graduate work involved investigating the role of air-sea interactions over the North Atlantic Ocean and their downstream effects over the Eurasian continent. Ms. Arsenault was awarded a GSFC graduate internship for the summer of 2000, where she applied the catchment-based land surface model to small catchment site. She began working at GSFC under the auspices of GEST full-time in January 2001.

Dr. Julio T. Bacmeister received his Ph.D. in geophysical fluid dynamics from Princeton University in 1987, where his research concentrated on numerical simulation of stratified flow around obstacles. From 1987 until 1992, he worked as a postdoctoral fellow in the Atmospheric Chemistry and Dynamics Branch at GSFC. He joined the Middle Atmospheric Chemistry and Dynamics Branch at the Naval Research Laboratory in Washington D.C. in 1992, where he led the development of a two-dimensional chemical transport model, and established a research effort in atmospheric gravity wave dynamics. In 1998 Dr. Bacmeister joined the NASA Seasonal-to-Interannual Prediction Project (NSIPP) as a visiting scientist, where he has led efforts in atmospheric model development. His current interests include cloud and convection parameterization, and parameterization of orographic effects for tropospheric climate models. He has published over 25 refereed papers in the fields of gravity wave dynamics and parameterization and atmospheric transport.

Dr. Susanne E. Bauer is a research fellow with the Earth Institute at Columbia University in New York City. Her Ph.D. (2000) is from the University Hamburg, in Germany. Her dissertation work took place at the Max Planck Institute for Meteorology in Hamburg, Germany, where she developed a mesoscale atmosphere-chemistry model. After receiving her doctorate, she worked for two years as a postdoctoral researcher at the Laboratoire des Science du Climat et de l'Environnement, National Center for Scientific Research (France) (CNRS)/ Climate and Environment System Research Center (CEA), in Gif-sur-Yvette, Paris. Her primary interest is in atmospheric chemistry, especially heterogeneous chemical reactions between aerosols and gas-phase species.

Ms. Deborah Belvedere is the program assistant to the Water Cycle Office at GSFC. Her work supports scientific collaboration and coordination for NASA's Goddard Water and Energy Cycle (GWEC) research. Currently, she is involved in a NASA Energy and Water Cycle Study, GSFC's Water and

Energy Cycle crosscutting theme, and is about to start work with the Global Energy and Water Cycle Experiment (GEWEX) Americas Prediction Project. She has also participated in fieldwork with the Cold Land Processes Experiment. Ms. Belvedere is a member of the American Geophysical Union and the American Meteorological Society, and has received several awards, including the Division Peer Award for Support Service (2001); the Hydrological Sciences Branch On-the-Spot Award for Superior Performance (2000); the Laboratory for Atmospheres Outstanding Performance in Administrative Support Award (1998); and a Code 913 Performance Award (1996).

Mr. Timothy Berkoff received a B.S. degree in optics from the University of Rochester in 1988. He has published over 15 refereed publications, numerous conference proceedings, and has been awarded two patents in optical sensing. From 1988 to 1997, he worked at the Naval Research Laboratory, where he conducted laboratory experiments demonstrating novel interferometric and fiber Bragg sensing techniques. This experience also involved the design and field implementation of new fiber sensing techniques, including the successful demonstration of interferometric sensors on surface and submersible ships. In 1997, Mr. Berkoff joined Aerodyne Research, where he designed and flight-tested a new water vapor instrument based on a Zeeman-split argon discharge lamp. While at Aerodyne, he also gained experience in tunable diode laser spectroscopy for trace gas species and used simulation software based on the HITRAN database to identify complex spectral profiles. Mr. Berkoff joined GEST in 1999, and is working on developing and demonstrating lidar sensing methods and instruments for atmospheric measurements. He designed and modeled receiver optics for a Raman airborne spectroscopic lidar instrument, and has experimentally demonstrated the remote detection of Raman scattering using a holographic optical element as a dispersive telescope. Currently, Mr. Berkoff is the instrument manager for the Micro-Pulse Lidar Network (MPLNET) where he is responsible for maintenance of existing MPL systems and the design and development of lidars for MPLNET.

Dr. Huisheng Bian received a B.S. degree in atmospheric science from Nanjing University in 1985, a M.S. in 1988, and a Ph.D., both in 2001, from the University of California, Irvine. From 1988 to 1995 she worked in Chinese Meteorological Academy as an assistant researcher, where her interest was regional air quality modeling. Her doctoral work focused on improving, validating, and applying a University of California, Irvine (UCI) global chemistry transport model for tropospheric ozone simulation, and on developing a module (Fast-J2) to accurately simulate stratospheric photolysis in global chemistry models. Upon graduation, Dr. Bian became interested in atmospheric aerosols, their distribution, and their photolytic and heterogeneous impacts on tropospheric chemistry. Her current major research interest involves developing a unified tropospheric and stratospheric chemistry transport model to be applied to Earth Observing System (EOS)-Aura data and problems in the global dimensions of multiscale air quality.

Dr. Eric Bucsela is an associate research scientist at GEST. Dr. Bucsela received a B.S. in physics from Emory University in 1983, a M.S. in electrical science from the Department of Electrical Engineering at the University of Michigan in 1986, and a Ph.D. in physics from the University of Michigan in 1994. At Michigan, he conducted research in aeronomy of the dayglow and developed instrumentation for *in situ* measurements and remote sensing of the atmosphere. He completed a postdoctoral fellowship at the Naval Research Laboratory (NRL) in 1997. At NRL, he developed models to investigate atomic and molecular excitation processes in the thermosphere. He also participated in the Defense Missile Satellite Program by playing a pivotal role in the calibration of the far-ultraviolet Special Sensor Ultraviolet Limb Imager (SSULI) spectrometer. Additional research and publications have involved studies of thunderstorm electrification processes. Such processes create sprites and other visible emissions above thunderstorms. In addition to his work at NRL, Dr. Bucsela has been active in research at GSFC through affiliations with Raytheon, SSAI, and, most recently, GEST. His work at GSFC has led to key insights about how observations of Raman scattering in the atmosphere can be used to infer cloud-top heights from space. Current research involves retrievals of critical trace gas constituents from satellite

measurements and the developing algorithms to extract total column and profile information for air pollutants. These algorithms will be adopted for use with the Ozone Monitoring Instrument (OMI) instrument on board the EOS Aura satellite as part of an international venture between NASA and the Royal Dutch Meteorological Institute.

Prior to his appointment at GEST, ***Dr. Sushil Chandra*** was a senior scientist at GSFC, where he conducted research in the fields of aeronomy, the ionosphere, and many other aspects of atmospheric science. He received a doctorate in physics from Pennsylvania State University. He has over 100 publications, most of which are in refereed journals, and most as first author. Dr. Chandra was involved in developing the first interactive ionosphere-atmosphere model. This coupled model played a major role in the interpretation of data obtained from several NASA satellites, including OGO-4, OGO-6, Explorer 31, ISIS, AE, AEROS-A, and AEROS-B. As a principal investigator for the Retarding Potential Analyzer on OGO-4, Dr. Chandra initiated several correlative studies using ionospheric and airglow data from a number of instruments. As a member of the AEROS Science Team, he initiated several collaborative studies of thermospheric density and temperature involving U.S. and German scientists. Later, Dr. Chandra moved to stratospheric ozone research, and made significant contributions to understanding the variability of ozone and temperature on different time scales ranging, from 27-day solar rotation periods to long-term trends. Currently, he is involved in developing new methods to derive tropospheric ozone from satellite data. This work has produced a unique approximately 25-year record of tropospheric column ozone in the tropics, and has helped in understanding seasonal and long-term changes in the tropical troposphere, including interannual variability associated with quasi-biennial oscillation (QBO) and El Niño events. Dr. Chandra is PI and co-I for several NASA-funded proposals. He was recently a co-I for the Wind Imaging Interferometer experiment on the UARS, and was a member of the Upper Atmosphere Research Satellite (UARS) Science Team from the beginning of the UARS program. Dr. Chandra became a visiting research scientist at GEST in April 2003.

Dr. Yehui Chang received a B.S. degree in physics from ECNU in 1982, and a Ph.D. in geophysical fluid dynamics from the Florida State University in 1994. He took a lectureship in physics at the Nanjing College of Economics from 1982 to 1987. From 1994 to 2001, he served as senior scientist at SAIC, studying climate and its variability and predictability, the variability and predictability of the Madden-Julian Oscillation, and short-term climate and dynamical seasonal forecasting. His specific interest is in developing and applying mathematical, numerical, and statistical methods to diagnose and characterize complex climate systems their responses to various forcings. Such methods are important not only in detecting and estimating forced signals, but they also provide a clue as to the natural variability of the climate system and the accuracy of data assimilation systems. Dr. Chang's publications deal with empirical orthogonal function (EOF) modeling, diagnostics of climate and data assimilation systems, dynamical seasonal prediction, and the impact of El Niño/Southern Oscillation (ENSO) on extratropical low-frequency noise in seasonal forecasts. Dr. Chang joined GEST in September 2001, as an associate research scientist.

Dr. Alexander M. Chekalyuk is a GEST investigator (GSFC, Wallops Flight Facility, Code 972) and research associate professor (Hampton University, VA). Dr. Chekalyuk received a B.S. degree in physics from Moscow State University (MSU) in 1977, and a Ph.D. in physics from MSU in 1982. He conducted laboratory research on new technologies for phytoplankton taxonomic analysis (2001-present, GSFC Wallops Flight Facility), airborne lidar technique for remote monitoring of aquatic photosynthesis (1998 – present, GSFC Wallops Flight Facility), submersible multispectral camera with laser illumination for small-scale structure studies (1997, Scripps Institution of Oceanography, CA), pump-during-probe techniques and instrumentation to measure photosynthetic characteristics of phytoplankton cells with microfluorometry and flow cytometry (1994-97, Woods Hole Oceanographic Institution, MA), developing a pump-and-probe lidar prototype for remote monitoring of photosynthetic activity of phytoplankton and terrestrial vegetation (1990-93, MSU), pulsed saturation fluorometry for retrieving

quantitative characteristics of complex organic molecules in liquid media (1975-89, MSU), nonlinear laser spectrometer and its application for quantitative measurements in two-component liquid media (1979-81, MSU), lidar applications in biological oceanography and environmental monitoring in the sea (1977-91, MSU), shipboard lidar system for remote monitoring of phytoplankton and dissolved organic matter in the sea water (1976-89, MSU), and developing a new technique and instrumentation to measure the concentration of fluorescent organic substances in liquid Raman-active solutions (1975-76, MSU). Dr. Chekalyuk served as research scientist at the Department of Physics, MSU, in 1977-94. He was a visiting scientist at Woods Hole Oceanographic Institution, MA, in 1994-1997. He served as a project scientist at Scripps Institution of Oceanography in 1997-1998, and was a National Research Council Senior Research Associate with GSFC/Wallops Flight Facility in 1998-2001.

Dr. Jiun-Dar Chern received a B.S. degree from National Taiwan University in 1984, and a Ph.D. in atmospheric sciences in 1994 from Purdue University, where he developed the Purdue Mesoscale Model (PMM) and applied the model to study lee vortices and winter cyclogenesis over the western United Stated. From 1995-2000, he worked as a research associate at Purdue University to develop the Purdue Regional Climate Model (PRCM) and a snowpack and sea-ice model. The model has been applied to study the 1988 U.S. drought, the 1993 midwestern U.S. flood, and the 1998 flood in Eastern Asia. In 2000, he joined GEST and worked at the Data Assimilation Office (DAO) at GSFC to improve the physical parameterizations of the finite-volume General Circulation Model (fvGCM) and the interface between the fvGCM and Goddard Earth Observing System (GEOS) 4 data assimilation system.

Dr. Warren B. Cohen is a research forester with the Pacific Northwest Research Station of the USDA Forest Service, and director of the Laboratory for Applications of Remote Sensing in Ecology at the Corvallis Forestry Sciences Laboratory in Oregon. He received his doctorate in forest science in 1989 from Colorado State University, with emphases on remote sensing and wildland fire behavior. Currently, he conducts research in remote sensing and related geographic and ecological sciences. His primary focus is translation of remote sensing data into useful ecological information, with significant activity in analysis and modeling of vegetation structure and composition across multiple biome types. His research involves spatially explicit modeling of ecological processes with significant attention to scaling from fine to coarse grain. He is assistant professor (courtesy) in three departments at Oregon State University (Forest Science, Geosciences, and Computer Science), where he intermittently teaches a graduate-level remote sensing and landscape ecology course, advises graduate students as both a major and minor professor, serves on interdepartmental committees, and gives guest lectures and seminars. He is on the editorial board of the journal *Remote Sensing of the Environment*.

Dr. Robert J. Curran is the director of GEST. He obtained his B.S. degree from Creighton University, and his Ph.D. in physics from the University of Arizona. He has over 30 years of experience with NASA, including 12 years as a research scientist at GSFC, and 12 years as a program manager at NASA Headquarters. His research experience includes radiation characteristics of clouds and aerosols. At NASA Headquarters he managed a wide variety of remote sensing, modeling, and sensor development projects associated with two separate research programs.

Ms. Marci P. Delaney is the program coordinator for GEST. She manages three student summer programs, coordinates the short-term visitors program, and organizes conference and workshops. She is also a member of the science, technology, engineering, and mathematics (STEM) Education Research & Technology (SERT) team, part of which handles the publication of a monthly newsletter and a semimonthly live Web-cast for the NASA Explorer Schools. Ms. Delaney received her B.S. degree in marine biology with a concentration in physics at the University of North Carolina in Wilmington in 1994. She earned her M.Sc. in biological oceanography at Memorial University of Newfoundland, St. John's, in 1998, and is in the process of completing her doctoral dissertation at Memorial University, with an expected graduation date of 2004. Her graduate research focus is on the effects of small-scale

turbulence on the marine microbial food web, with an emphasis on cold-ocean environments. She also continues to consult as a science content specialist to companies that produce educational materials for grades K-12.

Dr. Jiarui Dong received a B.S. degree in meteorology from Beijing Institute of Meteorology in 1989, a M.S. in computational mathematics in 1992 from the Chinese Academy of Sciences (CAS), and a Ph.D. in atmospheric sciences in 1997 from CAS, where he developed a coupled model for simulating drought and regional flood disasters. He earned a second doctorate in remote sensing in 2002 from Boston University. Dr. Dong's major accomplishments include remote sensing estimates of northern boreal and temperate forest woody biomass (carbon pools, sinks, and sources), improving the precision of simulated hydrologic fluxes in land surface models, developing and analyzing vegetation data sets from National Oceanic and Atmospheric Administration (NOAA) global data, and evaluating the utility of satellite-based vegetation parameters for climate simulation. Dr. Dong joined the GEST center at the Hydrological Science Branch at GSFC in 2002, working on land data assimilation for NASA's Seasonal-to-Interannual Prediction Project (NSIPP).

Dr. Oleg Dubovik received a B.S. and M.S. degrees in 1985 in physics (optics) from the Belarus State University (Minsk, Belarus). He received his Ph.D. in physics and mathematics from the Institute of Physics (Minsk, Belarus) in 1992. Dr. Dubovik began his research activities in 1985 at the Institute of Physics (Minsk, Belarus), as an assistant research staff scientist, and later as a full research scientist. From 1995-1997, Dr. Dubovik worked in the National Institute for Environmental Studies (Tsukuba, Japan) as visiting scientist supporting the Infrared Limb Atmospheric Spectrometer/Advanced Earth Observations Satellite (ILAS/ADEOS) project. Dr. Dubovik has worked at GSFC from 1997 to 2001 as a research scientist with SSAI, and has been a GEST member since then. During his career, he has been involved in conceiving, developing, and implementing inversion algorithms for deriving aerosol size distribution, refractive index (including single scattering albedo). He has also derived aerosol optical properties from multispectral solar transmission measurements and multiangular sky radiance measurements. At present, Dr. Dubovik is in charge of developing an inversion algorithm for the worldwide Aerosol Robotic Network (AERONET) project. He has authored 67 papers that have been published in refereed scientific journals.

Dr. Bryan Duncan received a B.S. degree in chemistry in 1991, and a Ph.D. in earth and atmospheric sciences in 1997 from the Georgia Institute of Technology in Atlanta, Georgia. His dissertation dealt with the effects of urban emission control strategies on the export of ozone and ozone precursors from the urban atmosphere to the troposphere. He was a postdoctoral fellow and research assistant from 1997 to 2001 in the Department of Earth and Planetary Sciences at Harvard University where he helped to develop the Goddard Earth Observing System (GEOS)- CHEM 3-D model of transport and chemistry, and conducted a model study of seasonal and interannual variations of carbon monoxide. He also worked on developing an estimate of the interannual variation of biomass burning for the 1980s and 1990s using satellite observations of smoke aerosols and fires. He then spent two years at the Swiss Federal Institute of Technology as a research scientist, performing model studies on the export of pollution from Europe and from wildfires in Indonesia. Now, as a visiting assistant research scientist, he contributes to model validation for the NASA Global Modeling Initiative (GMI).

Dr. Joseph L. Eastman received a B.A. degree in physics from the University of Minnesota. He was then employed by Dr. Walter A. Lyons in 1987 to aid in designing a ground conductivity model for use in simulating a lightning detection network, and also performed meteorological and dispersion modeling for the Kennedy Space Center. In 1990, Dr. Eastman was accepted to the graduate school at Colorado State University. Under the guidance of Dr. Roger A. Pielke, he achieved his masters in 1994 and his Ph.D. in ecology in 1999. His most recent work concentrates on assessing climate change, with special examination of the relative contributions of CO_2 and human-induced land change. In his postdoctoral

appointment, he was in charge of providing direction for the Long Term Ecological Research (LTER) national modeling efforts on massively parallel platforms. This included coupling meteorological models to synchronous and asynchronous ecosystem models. In his last research associate position under Dr. Roger Pielke, he continued regional climate research using coupled atmospheric and ecological models. He is currently investigating the effects of land-surface interactions on hurricanes and the impact of rivers on regional climate.

Mr. Thomas F. Eck received a B.S. degree in meteorology from Rutgers University in 1977 and an M.S. in meteorology from the University of Maryland, College Park in 1982, where his major interests were in micrometeorology and atmospheric radiation. In 1981, he began work at GSFC and has continued working there in the Biospheric Sciences Branch, Code 923, for over 22 years. During his career, he has been involved in algorithm development and data analysis for the Nimbus-7 cloud climatology project. He was also active in instrument calibration, field instrument deployment, and data analysis for the Portable Apparatus for Rapid Acquisition of Bidirectional Observation of the Land and Atmosphere (PARABOLA) instrument project, addressing plant canopy bidirectional reflectance, and analysis of Advanced Very High Resolution Radiometer (AVHRR) satellite data for water vapor retrievals. Currently, he carries out instrument calibration and deployment, field experimentation, data analysis, and scientific research within the global Aerosol Robotic Network (AERONET) project. He has authored and coauthored over 65 refereed papers, with recent emphasis on studies of the optical properties of atmospheric aerosols, especially from biomass burning and fossil fuel combustion, and the attenuation of solar flux by aerosols.

Dr. Ronald Errico received a B.S. degree in physics from the University of Arizona in 1974, where he also took several graduate courses in meteorology. His received a Ph.D. in meteorology in 1979 from the Massachusetts Institute of Technology. With E.N. Lorenz as his advisor, his dissertation, entitled “The partitioning of energy between geostrophic and ageostrophic modes”, examined the fundamentals of why the atmosphere is quasigeostrophic. It won the department’s award for best dissertation that year at the recommendation of Jules Charney. Applications of this dissertation work have continued throughout his career. After completing his degree, Dr. Errico joined the Advanced Study Program at the National Center for Atmospheric Research (NCAR) as a postdoctoral researcher, followed by a staff appointment in 1981 in the Large-Scale Dynamics Section of NCAR’s Atmospheric Analysis and Prediction Division. In 1994, he was appointed senior scientist in the Climate and Global Dynamics Division. During his tenure at NCAR, Dr. Errico took sabbaticals at the Naval Research Laboratory in Monterey from March 1989 to April 1990, and at the European Centers for Medium Range Weather Forecasts (ECMWF) for seven months in 1996. He left NCAR to join GEST for work at GSFC’s Data Assimilation Office (DAO) in July 2002. Since 1992, he has been chief organizer of eight international workshops, including four of the five international workshops on the Application of Adjoint Models in Dynamic Meteorology, and four on various aspects of data assimilation. His past work has included examination of atmospheric balance, development and application of atmospheric adjoint models, atmospheric predictability, scale analysis, regional climate modeling, and data assimilation. He developed NCAR’s Mesoscale Data Assimilation System, which is currently the only weather prediction model with a complete and useful physics adjoint.

Mr. Hui Feng joined GEST through Hampton University in November 2002 as a research associate. He received a B.S. degree in radio physics from the East China Normal University in 1983, and a M.S. degree in oceanography from the University of New Hampshire in 1996. Prior to joining GEST, Mr. Feng spent a few years as a software development engineer with an industrial company. He has experience in applied mathematics, oceanography, remote sensing applications, and software development. His specific research interest is in the area of inverse algorithms for remotely sensed signals to recover oceanic geophysical parameters. He is currently also working towards a Ph.D. at UNH, where his research is focused on developing inversion algorithms for ocean color spectra to retrieve in-water optically active

constituent parameters. His work at GEST has focused on improving the altimeter sea state bias correction algorithm.

Dr. Carlos Garcia received a B.S. degree in physics from the State University of Campinas (Brazil) in 1977. He received his M.Sc. (1986) and Ph.D. (1989) degrees from the University of Southampton, England. From 1979 to the present he has worked at the Department of Physics, University of Rio Grande (Brazil), as a lecturer and researcher in the fields of physical and satellite oceanography. Dr. Garcia has served as head of the Department of Physics (1994-1996) and rector of the University of Rio Grande (1997-2000). His activities at the university include lecturing, research, and supervision of undergraduate and graduate students on the fields of physical and satellite oceanography. He is coordinator of the Group of High Latitudes Oceanography (http://www.goal.ocfis.furg.br), which develops oceanographic research in the Southern Ocean within the Brazilian Antarctic Program.

Dr. Virginia Garcia received a B.S. degree in oceanography from Federal University of Rio Grande, Brazil, in 1983. She received her Ph.D. (1989) from the University of Southampton, England in Biological Oceanography. Her dissertation involved primary production and physiological studies with the bloom-forming phytoplankton *Gyrodinium aureolum*. From 1991 to the present, she has been working at the Department of Oceanography, Federal University of Rio Grande (Brazil), as lecturer and researcher in the fields of biological oceanography, primary production, and phytoplankton ecophysiology. Her research interests also include physiology and ecology of harmful marine microalgae. Dr. Garcia was coordinator of the postgraduate program on biological oceanography at FURG, in 1994-1995, and has been part of the postgraduate committee since 1994. Her activities at the Rio Grande University include lecturing, research, and supervision of undergraduate and graduate students.

Originally from Argentina, ***Dr. Santiago Gassó*** obtained a master's degree from the University of Buenos Aires (1992) in applied physics, working on modeling water pressure in polymer reservoirs. He moved to the U.S., where he completed his doctoral dissertation at the University of Washington, Seattle in 2001, specializing in the role of ambient humidity on aerosol optical properties as measured by *in situ* instrumentation and satellite observations. Currently, he is working in a Navy-sponsored project to simulate global visibility conditions with an aerosol transport model. In addition, he is funded by NASA and Inter-American Institute (IAI)/ National Science Foundation (NSF) to conduct studies on aerosol mass concentration as estimated by satellite, modeling, and *in situ* methods.

Dr. Charles K. Gatebe received B.Sc. and M.Sc. degrees in meteorology, mathematics, and physics, in 1990, and meteorology, in 1994, respectively, from the University of Nairobi, Kenya, and his doctorate in atmospheric sciences from the University of Witwatersrand, South Africa, in 1999. He holds the position of lecturer in the Institute of Nuclear Science, University of Nairobi, where he teaches courses on air pollution using nuclear related techniques. He came to GSFC in 1999 as a resident research associate of the Universities Space Research Association (USRA). He is currently an atmospheric scientist at GEST, and is on leave from his faculty position in Kenya. Dr. Gatebe's research experience includes developing a simple Gaussian model to estimate motor vehicle emissions from line sources (*e.g.,* highways) in Nairobi, *in situ* measurements of aerosols and gases, and characterizing aerosol sources using statistical and trajectory methods. He has been involved in International Atomic Energy Agency (IAEA)-coordinated research project on air pollution using nuclear-related analytic techniques, and was a member of the United Nations Environmental Programme (UNEP)/World Health Organization (WHO), Global Environmental Monitoring System (GEMS)/Air team of experts from 1994-1995. Dr. Gatebe has been involved with modification of NASA's Cloud Absorption Radiometer to provide a modern data acquisition system and UV optical channels suitable for remote sensing of aerosols. He has participated in several field campaigns, and most recently participated in the Southern African Regional Science Initiative (SAFARI)-2000 field experiment in Southern Africa, which took place from August-September, 2000 and also Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) 2001, USA

eastern coast, July–August 2001. In both experiments he made measurements using NASA's Cloud Absorption Radiometer aboard the University of Washington's CV–580 aircraft. Currently, he is interested in remote sensing of aerosols and bidirectional reflectance distribution functions to better understand their roles in global change. Dr. Gatebe was recognized for his work as a fellow of Global Change System for Analysis, Research, and Training (START) during the 5th International Geosphere Biosphere Programme (IGBP)-Scientific Advisory Committee meeting in Nairobi, Kenya, 1998, and is the winner of the 2000 World Meteorological Organization Young Scientist Award.

Mr. Jonathan C. Gottschalck received both his B.S. and M.S. degrees in meteorology from the Pennsylvania State University in 1994 and 1996, respectively. While in graduate school his research focus was in the area of land surface processes, studying the impacts of doubled CO_2 on canopy transpiration using two soil-vegetation-atmosphere transfer models. His work studied these impacts from the vegetation canopy scale to the full global scale; two published papers resulted from this work. After leaving the Pennsylvania State University, Mr. Gottschalck worked as a research associate at the University of Miami from 1997-2001. During this time, he worked in a variety of research areas, two of which included boundary layer and tropical meteorology. He developed a stratus cloud climatology using data from the Atmospheric Radiation Measurement Program Southern Great Plains Site in Oklahoma. Moreover, he investigated the relationship between the Madden Julian Oscillation (MJO) and El Niño. While at the University of Miami, he also taught undergraduate weather forecasting classes and acted as the university meteorologist for all public and press inquires. He joined GEST in February 2001, and is currently a research associate working in the Hydrological Sciences Branch at GSFC. His research has mainly focused on work with satellite precipitation and vegetation datasets and their impact on land surface simulations.

Dr. Mircea Grecu received a B.S. degree from the Technical University of Civil Engineering, Bucharest, Romania in 1993, and a M.S. in civil engineering from the University of Iowa in 1996, followed by a Ph.D. from the same university in 1999. After a postdoctoral association with the University of Connecticut, he joined GEST in 2002. Dr. Grecu's research interests include rainfall estimation from space and ground observations, assimilation of satellite observations in atmospheric and hydrologic models, and short term atmospheric and hydrologic forecasting. He is currently involved in the Tropical Rainfall Measuring Mission (TRMM) project in progress at the Mesoscale Atmospheric Processes Branch at GSFC. His work focuses on refining and extending algorithms to estimate rain from TRMM observations. Specifically, Dr. Grecu investigates the combined use of active and passive microwave observations to estimate rainfall by employing radar and radiative transfer models in a variational estimation framework.

Dr. Guojun Gu is an assistant research scientist at GEST. He received a B.S. in atmospheric physics from Nanjing University in 1986, and a Ph.D. in meteorology and physical oceanography from the Rosenstiel School of Marine and Atmospheric Science of the University of Miami in 2001. Prior to joining GEST, he was a postdoctoral research scientist at Columbia University. Dr. Gu's research is primarily in the field of tropical meteorology, which includes tropical waves, the Intertropical Convergence Zone, tropical precipitation and its variability on various spatial and temporal scales, and air-sea interactions. He is currently involved with the Tropical Rainfall Measuring Mission (TRMM) science project at GSFC's Mesoscale Atmospheric Processes Branch.

Dr. Bruce Guenther completed his doctorate at the University of Pittsburgh in 1974. He became a member of the research staff at GSFC, and worked there for over 15 years as project scientist on the Earth Observing System (EOS)-AM Project, responsible for calibration and data product validation.
Dr. Guenther developed the Moderate Resolution Imaging Spectroradiometer (MODIS) Characterization Support Team, and was responsible for the first publicly available EOS data sets. He then became a systems engineering fellow at Lockheed Martin Missiles Space Operations, working on the National

Polar-orbiting Operational Environmental Satellite System (NPOESS) system. Dr. Guenther returned to GSFC under the auspices of GEST as leader of the NPOESS Preparatory Project sensor calibration and data product validation effort. He has published extensively in the peer-reviewed literature, and has made presentations at many scientific meetings.

Dr. Mohan L. Gupta received a Ph.D. in earth system science from the University of California, Irvine, in 1996. His doctoral work focused on developing, validating, and applying global photochemical transport models to study the chemical balance of the natural and perturbed troposphere. He also worked extensively on the use of isotopes to study the budget and trend analysis of long-lived species, such as methane. Later, Dr. Gupta joined UCLA to work on testing and validating atmospheric chemistry components of the Earth System Model, which is comprised of atmospheric and oceanic general circulation models. From 1999 to 2001, he worked at ICF Consulting as a senior associate, and at the Electric Power Research Institute as a project manager on projects related to air quality and mercury/nitrogen surface deposition issues. In addition to atmospheric trace gas related issues, atmospheric isotopes and biogeochemistry, Dr. Gupta's current research interests involve problems involving regional and urban air quality, surface deposition, and atmospheric toxic gases.

Dr. Hiroo Hayashi completed his education at Hokkaido University in Sapporo, Japan. His doctorate was awarded in 2001 for a dissertation on inertial instabilities in the tropical atmosphere, detected using space-based and *in situ* data. After graduation, he was a postdoctoral fellow at the National Institute for Environmental Studies in Tsukuba, Japan, where he worked on descending motion in the polar vortex using trace-gas data from the ILAS satellite instrument. Dr. Hayashi joined GEST in April 2002, and has been working within the GSFC Global Modeling and Assimilation Office, assimilating tropospheric ozone using satellite ozone data.

Dr. Jacques Hinderer, a GSFC Visiting Fellow at GEST, completed his doctorate in geophysics in 1980 at the University Louis Pasteur, Strasbourg (France); in 1987, he received a doctorat d'etat (habilitation) in geophysics from the same university. He joined CNRS (Centre National de la Recherche Scientifique et Technique) as researcher in 1986 and became senior research scientist in 1996. He was on sabbatical leave in 1991-1993 at McGill University in Montreal, Canada under the auspices of an international research fellowship from NSERC (National Sciences and Engineering Research Council of Canada). He is the present chair of the geodynamics group, consisting of seven people, at the Institut de Physique du Globe de Strasbourg (IPGS) and the director of the Strasbourg Gravimetry Observatory, in charge of the superconducting and absolute gravimeters operating in France. Since 2001, he has also served as vice-chair of the IPGS. He has been secretary of the Global Geodynamics Project (GGP) since 1997, an international network of superconducting gravimeters. In 1990, he received Young Scientist Award of the European Geophysical Society, and in 1998, he received the Antoine d'Abadie Prize of the French Academy of Sciences. Dr. Hinderer has published over 100 papers in refereed scientific journals, and serves on numerous national and international committees.

Dr. Susan Hoban received her Ph.D. in astronomy from the University of Maryland in 1989. She conducted research in cometary science at GSFC, first as a National Research Council fellow, then as part of Universities Space Research Association (USRA) Visiting Scientist Program, from 1989-1993. In 1993, she began working on the use of information systems in science and education. In 1996, she received the NASA Special Service Award for her work on Web-based educational outreach. Dr. Hoban joined the University of Maryland Baltimore County in the Computer Science and Electrical Engineering Department in 1996 as part of the Center of Excellence in Space Data and Information Science (CESDIS) at GSFC. From 1998-1999, Dr. Hoban served as acting associate director of CESDIS, and from 1999 through the conclusion of its contract in 2000 as acting director. Dr. Hoban is currently an associate research scientist at GEST, spokesperson for the Information Science and Education Technology research group, and PI on the NSF-funded "Virtual Telescopes in Education" and "Educating with Virtual

Experience" grants. Her interests include scientific information systems, digital library technologies, developing and implementing information technologies for science, technology, engineering, and mathematics education.

Mr. Kevin Horgan is a researcher at the Microwave Instrument Technology Branch (MITB) at GSFC. He received his B.S. and M.S. degrees in electrical engineering in 1999 and 2003, respectively, from the University of Massachusetts, Amherst. His previous research, conducted at the Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts, focused on the development of a Ka-band polarimetric radiometer and polarimetric calibration techniques. His current research focuses on polarimetric radiometry and the design of an ultra-stable L-band radiometer for the Aquarius satellite mission to measure global sea surface salinity (SSS).

Dr. Nai-Yung (Christina) Hsu received a Ph.D. in atmospheric sciences in 1991 from the Georgia Institute of Technology, where her research interest was general circulation model (GCM) modeling of ozone photochemistry and transport processes in the stratosphere. In 1994, Dr. Hsu moved to Maryland and began her studies on remote sensing of tropospheric aerosols. She has published over 20 refereed papers, the most recent focusing on remote sensing of aerosols and aerosol-climate interactions. She is a member of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Total Ozone Mapping Spectrometer (TOMS) Science Teams, where her focus is on the properties of aerosols in the ultraviolet (UV) and visible regions of the spectrum, and determining the radiative forcing due to tropospheric aerosols. Her research experience includes developing near-real-time satellite retrievals of aerosols using measurements from Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and MODIS-like instruments over the oceans and over bright-reflecting dust source regions for field campaigns. Dr. Hsu is currently an associate research scientist at GEST, performing her work at GSFC.

Dr. S. Daniel Jacob received a B.E. degree (with honors) in civil engineering from the Madurai Kamaraj University, Madurai, India (1987), and a master's degree in ocean engineering from the Indian Institute of Technology, Madras, India (1991). He worked for a few years at the Indian Space Research Organization analyzing synthetic aperture radar data of ocean surface waves and other satellite data before pursuing a doctorate at the University of Miami. He was awarded his Ph.D. in meteorology and physical oceanography from the University of Miami Rosenstiel School of Marine and Atmospheric Science in 2000. Dr. Jacob's dissertation examined the upper ocean heat budget variability due to oceanic mesoscale variability and its effect on the intensification of tropical cyclones. He then worked as a postdoctoral research associate at the University of Miami, where he was involved in acquiring oceanographic data from the National Oceanic and Atmospheric Administration (NOAA) hurricane hunters, using expendable probes, and in the Eastern Pacific as part of the Eastern Pacific Investigation of Climate project. He was appointed assistant research scientist at GEST in May 2002, based in the Oceans and Ice Branch at GSFC. As a member of Aquarius Science Team, Dr. Jacob conducts research on the effects of surface forcing and ocean mixing on sea surface salinity, and also leads an effort to identify an appropriate mixing scheme for use in coupled predictive models of hurricane intensity.

Ms. Urszula Jambor received her B.Sc. degree in atmospheric and oceanic sciences from McGill University, Canada, in 1997, and her M.S. in meteorology from the Pennsylvania State University in 2000. Her graduate work involved evaluating ice clouds produced by parameterizations in numerical prediction models with comparison to corresponding remotely sensed measurements. This research developed her interest in applying remotely sensed data to numerical modeling studies. In the fall of 2000, she joined GEST to begin working at GSFC on the Global Land Surface Data Assimilation System (GLDAS) project.

Dr. Daniel E. Johnson received a B.S. degree in mechanical engineering from the University of Minnesota, Minneapolis, in 1988, and a M.S. in meteorology and Ph.D. in atmospheric science from the

University of Wisconsin, Madison in 1991 and 1997, respectively. His primary research interests while in graduate school included developing and implementing a detailed ice-microphysical package for cloud-resolving models to study winter storms. Dr. Johnson was awarded two fellowships with the NASA Graduate Student Researchers Program (GSRP) in 1994, and completed his doctoral research and dissertation at GSFC over the following two years. In 1996, he joined the Laboratory of Atmospheres at GSFC as a postdoctoral fellow and began conducting research on deep tropical cloud systems using the Goddard Cumulus Ensemble (GCE) model. In 2001, Dr. Johnson joined GEST, and is currently working on developing the GCE model and conducting simulations of deep convective cloud systems in both tropical and midlatitude regions. Dr. Johnson serves as a reviewer for the *Journal of the Atmospheric Sciences*. In December 2001, Dr. Johnson received an Outstanding Scientific Research Award for his research and work in the Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, GSFC.

Dr. Peter Merheim Kealy completed a B.Sc. degree in geophysics from Reading University, UK in 1987, and Ph.D. in geophysics from University College, Durham, UK in 1990. During his doctoral and postdoctoral studies, he worked in Australia and Africa on a variety of remote sensing instrumentation and ground processing systems, including thermal radiometers, thermal lasers, and interferometers. Between 1992 and 1997, he was an optical engineer in the Earth Sciences Division of European Space Agency (ESA)- European Space Research and Technology Centre (ESTEC) in the Netherlands, working on sensor and algorithm aspects of the AATSR (radiometer) and MERIS (spectrometer) missions. Between 1998 and 2003, he worked for Raytheon as a systems engineer and program manager on National Polar-orbiting Operational Environmental Satellite System (NPOESS)- Visible Infrared Imager Radiometer Suite (VIIRS) (radiometer) and NPOESS Aerosol Polarimeter Sensor (APS). In 2003, he came to work for the NPOESS Preparatory Project (NPP) as a group leader within the project science group, with responsibility for algorithm-related system optimization.

Dr. Richard Kelly received his B.Sc. (with honors) from the University of Manchester, UK, in 1988, and an M.A. (with distinction) in glaciology from Wilfrid Laurier University, Canada in 1990. He completed his Ph.D. in 1994 in the Department of Geography at Bristol University, UK. Since 1994, he has been a lecturer in physical geography at Birkbeck College, University of London, UK, where his major research activities have involved remote sensing of snow and ice using active and passive microwave Earth observation systems. His most recent research interests include combining optical and microwave sensors for UK snow monitoring and using synthetic aperture radar to monitor the mass balance of an ice cap in Norway. He was a participant at the inception of the Snow and Ice Special Interest group within EARSeL. Dr. Kelly has published in international research journals and has made presentations at international conferences. He is a member of the UK's Photogrammetry and Remote Sensing Society (formed from a merger of the former Remote Sensing Society and the Photogrammetry Society), the International Glaciological Society, and the American Geophysical Union.

Dr. Maeng-Ki Kim completed his education in South Korea. He received a B.Sc. degree in Earth science from the Kongju National University (1988), a master's degree in atmospheric sciences at the Seoul National University (1990), and a Ph.D. in atmospheric science from the Seoul National University (1997). He examined the atmospheric circulation patterns induced by global warming and warming mechanisms related to land-atmosphere interactions in the Northern Hemisphere. Dr. Kim is currently an assistant professor in the Department of Atmospheric Science at Kongju National University, performing research on climate dynamics, and taught from 1999-2003. He has been a Goddard Visiting Fellow at GEST for his sabbatical year since late 2003, based at the Laboratory for Atmospheres at GSFC.

Dr. Hyung Rae Kim received a B.Sc. degree from the Department of Geology at Yonsei University, Seoul, South Korea in 1993, and a master's degree in the geophysics of Earth and atmospheric sciences at Purdue University in 1997. His master's thesis examined aspects of the external geomagnetic field from POGO satellite data using satellite-based magnetic data that measured the signals due to electromagnetic

current systems occurring especially around the dip equator (called the equatorial electrojet) in the daytime. He investigated the nature of the equatorial electrojet in terms of local time and longitude. Dr. Kim continued studying the Earth's geomagnetic field in the Department of Geological Sciences at Ohio State University under Dr. R. von Frese's direction, and earned a Ph.D. in June of 2002. His dissertation investigated the lithospheric magnetic anomalies from Ørsted satellite magnetometer data and near-surface (*i.e.,* ground, shipborne, and airborne) data in Antarctic. After he finished his doctorate, Dr. Kim spent one year as a postdoctoral researcher at Ohio State University working for the Antarctic Digital Magnetic Anomaly Project (ADMAP) and in preparation for the Mars Data Analysis Program. While in Columbus, he also prepared several proposals for Antarctic research, Mars magnetic field study, and geopotenital analysis of North America (*e.g.,* Earthscope) among others. Since September 2003, Dr. Kim has been a junior postdoctoral fellow at GEST and GSFC, where his research activity has focused on developing an advanced model of the Antarctic magnetic field anomaly as an active member of ADMAP, in cooperation with other members of the international geophysical community.

Dr. Anuradha Koratkar graduated with a B.Sc. degree in mathematics, physics, and chemistry from the Osmania University in India (1981), a master's degree in astronomy from the State University of New York (1989), and a Ph.D. in astronomy from the University of Michigan (1990). Her doctoral dissertation examined the dynamics and kinematics of the broad line region in active galactic nuclei. She was a research scientist at the Space Telescope Science Institute for 10 years, where she was involved in many aspects of science operations for the Hubble Space Telescope mission. She has also been a scientific lead on IT projects that will optimize science operations and maximize scientific returns. Dr. Koratkar has received several awards for her activities related to the Hubble Space Telescope. Her innovative ideas have also received recognition via the NASA Software of the Year Award, Honorable Mention for 2001. In 2003, she came to GEST as a visiting associate research scientist. She has published over 50 articles in refereed journals, including 20 papers in the field of active galactic nuclei physics. Dr. Koratkar's science community activities involve serving on several peer review committees and working groups, and organizing scientific and technical meetings for the Space Telescope Science Institute and the larger astronomical community.

Dr. Nickolay A. Krotkov received a B.S. degree from the Moscow Institute of Physics and Technology in physics in 1983, a M.S. (with honors) in remote sensing in 1985, and a Ph.D. in oceanography (physics and mathematics) in 1990 from the P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, where his major research the used polarization properties of light in oceanic remote sensing. Since 1993, he worked in close collaboration with TOMS scientists to study volcanic clouds, surface and underwater ultraviolet radiation, and aerosols. Dr. Krotkov has over 15 years' of experience in UV radiative transfer modeling and satellite- and ground-based UV data analysis. He has published over 30 refereed papers, the most recent of which concentrate on UV remote sensing of volcanic emissions and satellite estimates of surface UV irradiance. Dr. Krotkov is a senior research scientist at GEST.

Dr. Sujay V. Kumar received a B. Tech. in civil engineering from the Indian Institute of Technology, Bombay, in 1996, and an M.S. in civil engineering from North Carolina State University, Raleigh, in 1998. He continued at North Carolina State University for a Ph.D. in civil engineering, with emphasis on computer-aided, high-performance computing applications. Dr. Kumar finished his Ph.D. in January 2002. He is currently an assistant research scientist at GEST.

Dr. Prasun K. Kundu received a B.S. degree (with honors) in physics from Calcutta University, India, in 1974, and a M.S. in physics from the Indian Institute of Technology, Kharagpur, India, in 1976. He then joined the High Energy Physics Group at the University of Rochester in New York, where he earned his doctorate in 1981 in theoretical physics for his work on a new class of exact and asymptotic solutions of the Einstein general relativity field equations. From 1980-1982, he was a postdoctoral research associate at the Enrico Fermi Institute, University of Chicago, and subsequently was an instructor from 1982-1985

at the University of Utah, Salt Lake City. Dr. Kundu's postdoctoral work addressed mathematical problems in general relativity and quantum cosmology. In 1985, he joined the Department of Physics and Astronomy at Ohio University, Athens, as assistant professor, where he taught graduate and undergraduate courses in physics and continued research in relativistic gravitation theory. Since 1992, he has worked at the Climate and Radiation Branch, GSFC, on various rainfall statistics problems related to the Tropical Rainfall Measurement Mission (TRMM), and other satellite- and ground-based remotely sensed precipitation measurements. He was awarded an Exceptional Scientific Support Award in 2000. Dr. Kundu is currently an associate research scientist at GEST.

Dr. Kwo-Sen Kuo received his B.S. degree in atmospheric science in 1983 from National Taiwan University, Taiwan, Republic of China, his M.S. in meteorology in 1987 form the South Dakota School of Mines and Technology, and his Ph.D. in atmospheric science in 1995 from Colorado State University. Although his main interest of research is in atmospheric radiative transfer and its applications in remote sensing, he also has expertise in image processing and interpretation, using both conventional methods and artificial intelligence. He developed a three-dimensional radiative transfer model as his dissertation research. Dr. Kuo joined South Dakota School of Mines and Technology (SDSM&T) as a research scientist in 1994, continuing his research in radiative transfer modeling and cloud-field property analyses. His position at SDSM&T changed to research assistant professor in 1995 and to assistant professor in 1996 while engaging in a variety of research topics, including retrievals of cloud and aerosol properties using satellite data, investigation of cloud three-dimensional effects on retrievals, cloud mask development for Advanced Spaceborne Thermal and Emissions Radiometer (ASTER) and Clouds and the Earth's Radiant Energy System (CERES), and classification of objects within satellite images. In July 1997, Dr. Kuo moved to the University of Alabama in Huntsville to take a research scientist position, and continued his research. In late 1999, he started investigating improvements to precipitation retrievals using spaceborne radar. He started his position working in the GEST program in January 2002, as an associate research scientist with Caelum Research Corporation, and continues his work creating a more-realistic physical radiative transfer model for the Global Precipitation Measurement mission.

Dr. Reginald Lancaster received a B.S. degree in physics from Bethel College in 1990, and a Ph.D. in astronomy in 1997 from Boston University, where his major research interest was in atmospheric remote sensing. During his career, he has developed various imaging systems and spectrometers and has carried out experimental research focusing on several atmospheric regions of the Earth, ranging from the troposphere to the exosphere. After beginning his career studying atomic oxygen and hydrogen in the tenuous upper atmosphere, he joined the University of Michigan in 1997, where the focus of his research shifted to that of remotely measuring ozone in the lower atmosphere. In 1999, he began work as a research meteorologist onsite at GSFC, where he now conducts research in the field of cloud remote sensing.

Dr. Roger Lang is a professor in the Department of Electrical and Computer Engineering at George Washington University, Washington D.C. He received his M.S. in electrical engineering in 1964 and his doctorate in electrophysics in 1968, both from the Polytechnic Institute of Brooklyn. He was a postdoctoral researcher at the Courant Institute of Mathematical Sciences at New York University from 1968-1969, working on wave propagation in random media with Joseph B. Keller. He has held visiting appointments at the Joint Research Centre, Microwave Signature Laboratory, at Ispra, Italy; the Naval Research Laboratories, Radar Division, in Washington D.C., and GSFC. He is a Fellow of the IEEE, cited for contributions to microwave modeling of vegetation.

Dr. David Lary completed his education in the United Kingdom. He received a First Class Double Honors B.Sc. degree in physics and chemistry from King's College London (1987) along with the Sambrooke Exhibition Prize in Natural Science, and a Ph.D. in atmospheric chemistry from the University of Cambridge, Churchill College (1991). His dissertation described the first chemical scheme

for the European Centers for Medium Range Weather Forecasts (ECMWF) numerical weather prediction model. He then held postdoctoral research assistant and associate positions at Cambridge University until receiving a Royal Society University Research Fellowship in 1996, also at Cambridge. A Royal Society University Fellowship is one of the most prestigious awards for young scientists in the UK. The Royal Society is the world's oldest scientific academy in continuous existence, and has been at the forefront of enquiry and discovery since its foundation in 1660. From 1998 to 2000, Dr. Lary held a joint position at Cambridge and the University of Tel Aviv as a senior lecturer and Alon fellow. An Alon Fellow is the highest award Israel can give a young scientist. In 2000, the chief scientific adviser to the British Prime Minister and Head of the British Office of Science and Technology, Professor Sir David King, recommended that Dr. Lary be appointed as a Cambridge University lecturer in chemical informatics. In 2001, Dr. Lary joined GEST as the first distinguished GSFC fellow in Earth science at the invitation of Richard Rood (now head of Code 930). His current work addresses chemical data assimilation, and the use of neural networks to parameterize various aspects of atmospheric chemical simulation and to describe the spatial and temporal dependence of tracer-tracer correlations

Dr. Daniel DeForrest Laughlin received a B.A. degree in history and political sciences at Warren Wilson College (1985), followed by an M.A. in ancient history from the University of Newcastle-upon-Tyne (1986). After a decade of teaching at an assortment of colleges and universities, he undertook a course of study at American University that culminated in a Ph.D. in education (2001). Dr. Laughlin's research focused extensively on the use of information technology in education and cognitive science. During the latter part of his degree work, he accepted a position at the university as an instructor, teaching courses on educational uses of technology, and was awarded a fellowship by the provost to perform research on the same topic. In 2002, Dr. Laughlin accepted a visiting researcher position at GEST to work with the Leading Educators to Applications, Research, and NASA-related Educational Resources in Science (LEARNERS) initiative. In 2003, he accepted a position as an assistant research scientist at GEST. He continues to work closely with efforts to enhance science, technology, engineering, and mathematics (STEM) education by developing tools that combine NASA data and solid, research-based learning theory. He is currently a member of the NASA's Learning Technologies Project board of advisors and the STEM Education Research and Technology team.

Mr. Rick Lawford received his undergraduate degree in physics in 1966 from the University of Manitoba (Brandon College) and carried out graduate studies in meteorology at the University of Alberta, receiving a M.Sc. in 1970, and McGill University from 1971-1973. Early in his career, he worked as a weather forecaster, research meteorologist, and professional trainer in meteorology. He also served as a regional chief of a scientific service division, a group of meteorologists working in applied climatology in Toronto, Ontario. He has served as an adjunct professor (geography) at the University of Saskatchewan and a lecturer in physics (Carleton University in Ottawa). Mr. Lawford worked for more than eight years for the University Corporation of Atmospheric Research (UCAR) with NOAA as the program manager for the GEWEX Americas Prediction Project. In this position, he managed grants, organized meetings, and developed planning documentation and reports for this continental-scale hydroclimatological experiment. Prior to working for UCAR, Mr. Lawford spent many years working in the fields of hydrology and meteorology with the Canadian government. In his last position, before moving to the U.S., he served as division chief for a research group in hydrometeorology at the National Hydrology Research Center in Saskatoon. He has also worked in the fields of science policy development (at the Canadian Ministry of State for Science and Technology), program planning, evaluation, and environmental policy development (at Environment Canada) in Ottawa. Mr. Lawford has recently been appointed Director of the International Global Energy and Water Cycle Experiment (GEWEX) Project Office (IGPO). He is a member of the American Geophys8ical Union, the American Meteorological Society, and the Canadian Meteorological and Oceanographic Society. His work is published on a broad range of topics, he frequently gives conference presentations, and has been listed in *International Who's Who*.

Dr. Myong-In Lee received his of B.Sc. and M.Sc. degrees in atmospheric sciences from the Seoul National University, Korea, in 1994 and 1996, respectively. In 2001, he received a Ph.D. degree from the same university, investigating cumulus parameterizations in a climate model for the tropical Madden-Julian Oscillation simulation, for which he was awarded a prize by the Korean Meteorological Society. Dr. Lee started his career as a postdoctoral researcher in the Climate and Environment System Research Center (CES), Korea, where he focused on developing systems for dynamical seasonal and sub-seasonal prediction. He also was a lecturer for a climate modeling class at Seoul National University in 2002. Dr. Lee joined GEST in 2003, and currently works at the Global Modeling and Assimilation Office at GSFC, performing atmospheric modeling and climate studies. He is interested in examining moist convective parameterizations in the NASA Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric general circulation model and warm-season diurnal cycle simulations over North America.

Dr. Shuhua Li received a B.S. degree from Nanjing Institute of Meteorology, China in 1984, and a M.S. from Macquarrie University, Australia in 1996. He obtained his Ph.D. degree in meteorology from Monash University, Australia in 2000. Dr. Li's research experience includes large-scale atmospheric circulation and energetics, tropical cyclone activity and climate change, and stratospheric dynamics and transport. Dr. Li joined GEST in April 2001, and has worked at the Global Modeling and Assimilation Office (GMAO) to evaluate the finite-volume Data Assimilation System (fvDAS) for reanalysis of stratospheric trace species for the period 1991-1995.

Dr. Lihua Li received a B.S. degree in electrical engineering from Tsinghua University, China in 1988, a M.S. in high-energy physics from the Chinese Academy of Sciences in 1991, and a Ph.D. in electrical engineering from the University of Massachusetts at Amherst in 2000. Before joining GEST, he was a research engineer in the Microwave Remote Sensing Laboratory, University of Massachusetts. His research interests are microwave and millimeter-wave remote sensor development, data analysis, and retrieval of cloud microphysical properties using cloud radar measurements.

Dr. Xiaowen Li received her B.S. degree in atmospheric sciences from Beijing University, China. She worked as an associate researcher in Chinese Academy of Meteorological Sciences for two years after she received her M.S. degree in 1994. Dr. Li finished her doctorate at the University of Chicago in 2002, studying cloud microphysics and radar meteorology. Her dissertation studied the evaporation in stratiform rain region using both 1-D and 2-D simulations. She joined GEST as a research associate in July 2002. Early in her career, Dr. Li pioneered research on direct radiative effects of anthropogenic aerosols in regional climate change. She was also a member of China-Japan East Asia monsoon study project, and participated in making observations of surface turbulence on the Tibetan Plateau from 1994 to 1996. Dr. Li currently studies the impacts of aerosols on cloud and precipitation systems using numerical models, and works to improve both bulk-type and bin spectra microphysical schemes in the Goddard Cloud Ensemble Model.

Dr. Liang Liao received his B.S. degree in radio physics and M.S degree in space physics from Wuhan University, Wuhan, China in 1982 and 1985, respectively, and his Ph.D. in meteorology from the University of Utah, Salt Lake City in 1993. His research interests include radio wave propagation, electric field scattering, and atmospheric radar and radiometer remote sensing of clouds and precipitation. Currently, he is a senior scientist at GEST under the auspices of Caelum Research Corporation.

Dr. Ruei-Fong Lin is currently an assistant research scientist at GEST. Dr. Lin received her B.S. degree in atmospheric sciences from National Taiwan University (NTU), Taiwan in 1990, and her M.S. and Ph.D. degrees in meteorology from Pennsylvania State University in 1993 and 1997, respectively. Before joining GEST, she spent eight months at NTU, working as a post-doctoral research scientist, followed by two years in Universities Space Research Association as a visiting scientist. Dr. Lin's expertise and research interests are numerical modeling of cirrus, cloud physics, and radiative transfer. She participates

in the Global Energy and Water Cycle Experiment Cloud Systems Studies (GESS) Working Group on Cirrus Cloud Systems (WG2). She, together with Dr. David O'C Starr, at GSFC, and Dr. Paul DeMott, at Colorado State University, leads the Cirrus Parcel Model Comparison Project of the Global Cloud Systems Studies (GCSS) WG2.

Dr. Xin Lin received a B.S. degree in meteorology from Peking University in 1990, and M.S. and Ph.D. degrees in atmospheric science from Colorado State University in 1992 and 1997, respectively. His doctoral research focused on meso- and large-scale observational studies in both the tropics and midlatitudes. He worked as a postdoctoral researcher and then as a research associate at Colorado State University between 1997 and 2001, where he learned about climate modeling, cloud parameterizations, and remote sensing. In July 2001, Dr. Lin joined GEST to lead research efforts to implement the next-generation cloud scheme in the GMAO model. He also works on simulating satellites in climate models, and using cloud model results to improve convective parameterizations in general circulation models.

Dr. Tom Low is the associate director of GEST. He received his B.A.Sc. in engineering science and a Ph.D. in physics from the University of Toronto. His specializations in cloud physics and precipitation formation have included laboratory studies, field measurements, and numerical modeling of the evolution of precipitation processes. His work in IR and microwave remote sensing has led to the development of surface boundary layer models for both marine and land surfaces. Dr. Low has been a research scientist and program manager in the private sector in the international community for over 20 years. He is also a trained weather forecaster, and has been named a Certified Consultant Meteorologist by the American Meteorological Society.

Dr. Alexei I. Lyapustin received a B.S. and M.S. in physics from Moscow State University in 1987, and a Ph.D. in aerospace remote sensing from the Space Research Institute, Moscow, Russia in 1991. Between 1993 and 1996, he was a principal investigator for the Russian Space Agency, processing remote sensing data from space station MIR. Before joining GEST in February 2002, Dr. Lyapustin was a research fellow for two years at the Universities Space Research Association (USRA), and an assistant research scientist in JCET at UMBC. Dr. Lyapustin actively works on 3-D radiative transfer over anisotropic nonhomogeneous surfaces, developing the method of spherical harmonics. At present, he develops applications for this new theory for generic aerosol retrievals and atmospheric correction for the Landsat ETM+, Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Scanning Radiometer (MISR), and the future National Polar-orbiting Operational Environmental Satellite System (NPOESS) Visible Infrared Imager Radiometer Suite (VIIRS) instrument. Dr. Lyapustin has delivered a series of lectures on aerosol retrievals and atmospheric correction on invitation from Boston University and UMBC. He has been an associate member of VIIRS Operational Algorithm Team (VOAT) since 2000. In 2004, he was selected a Science Team Member for the MODIS and NPOESS Preparatory Project (NPP) Science Teams.

Dr. Sarith Mahanama received a B.Sc. degree in engineering from the University of Peradeniya, Sri Lanka in 1993, and a Ph.D. in water and environmental engineering in 2000 from the University of Hong Kong, where his major research interest was water balance studies at the land-atmosphere boundary and predicting river discharges in large-scale river basins using atmospheric general circulation model-generated meteorological forcings. In 2000, he joined the Universities Space Research Association to work at the Hydrological Sciences Branch at GSFC. Later in 2000 he joined GEST, where he is still employed, performing his research at GSFC.

Dr. Ashwin Mahesh received a B.Sc. degree from Bangalore University in 1989, an M.B.A. from Pondicherry University in 1991, an M.S. in astronomy from Vanderbilt University in 1993, and a Ph.D. in geophysics from the University of Washington in 1999. Late in 1999, he joined Analytical Services and Materials, Inc. in Hampton, VA, and conducted research on nighttime cloud detection in the Arctic. In

September 2000, he began work at GEST. His current research interests include spectral and lidar remote sensing of cloud properties, climate change in the high latitudes, and radiation balance over Antarctica. He is also developing a standard atmosphere of Antarctica for use in climate models. In 2001, he compiled the first annual cycle of cloud properties over the high plateau. In between 2002-2003, he developed the first climatology of blowing snow in the Antarctic plateau.

Dr. Hank Margolis obtained a B.Sc. degree in forest management from the University of Vermont, an M.F. in forest ecology from the Yale School of Forestry and Environmental Studies, and a Ph.D. in ecosystem ecology and silviculture from Oregon State University. His research has concentrated on the ecophysiology of trees and forests, having worked in both boreal and tropical ecosystems. He has been a professor at Laval University in Quebec City, Canada since 1986, where he has taught courses on analysis of tropical forest ecosystems, agroforestry, and general silviculture. He has published over 50 refereed journal articles and has directed more than 25 graduate students and postdoctoral fellows. He became involved in the planning and execution of the NASA-led Boreal Ecosystem–Atmosphere Study (BOREAS) during the 1990s, and was responsible for the Canadian university component of this interdisciplinary field study. He was a Universities Space Research Association (USRA) visiting scientist and a National Research Council (NRC) senior research associate with the Biospheric Sciences Branch of GSFC in 1995 and 1996, respectively. He is currently the program leader and principal investigator of the Fluxnet-Canada Research Network. This network expands the scientific approach developed in BOREAS to a national scale.

Dr. Jesse Meng received a B.S. degree in atmospheric sciences from National Taiwan University, Taipei, Taiwan, in 1991, a M.S. and Ph.D. in meteorology from the University of Maryland, College Park, Maryland in 1997 and 2001, respectively. His research at the University of Maryland focused mainly on developing and implementing methods to estimate, monitor, and evaluate the Earth's land surface radiation and energy budgets from satellite observations. He joined GEST in March 2001 as a research associate, spending half of his time at GSFC's Hydrologic Sciences Branch (Code 974), and the other half at the National Oceanic and Atmospheric Administration (NOAA)/ National Centers for Environmental Prediction (NCEP)/ Environmental Modeling Center (EMC), working on the NASA/NOAA joint Global Land Data Assimilation System (GLDAS) project. The GLDAS project work involves generating near-real-time global land surface shortwave and longwave radiation fields based on satellite observations for land surface modeling, and evaluates the consequent changes in land surface states in response to variations in radiative forcing.

Dr. Ken-ichi Mizoguchi received a M.S. in oceanography from Kyushu University, Japan in 1994, a M.S. in oceanography from Florida State University in 1997, and a Ph.D. in oceanography from Florida State University in 2001. He was a visiting research associate at GEST from 2002 through 2004, and has been an assistant research scientist at GEST since 2004.

Dr. Gary A. Morris earned an A.B. degree in mathematics and physics from Washington University in 1989 and a Ph.D. in space physics and astronomy at Rice University in 1995. Upon graduation from Rice, he assumed a National Research Council (NRC) postdoctoral research position at GSFC, working on the development of trajectory mapping and trajectory chemical modeling. He then accepted a position as research assistant professor at the University of Maryland Baltimore County (UMBC) before moving on to a two-year visiting assistant professor position at Valparaiso University. At this point in his career, Dr. Morris' teaching duties became his primary focus. For the last four years, he has been the Wiess Instructor and Clinical Assistant Professor of Physics and Astronomy at Rice University, overhauling the instruction of introductory physics in the premedicine program. He has since won two awards for his outstanding teaching. Dr. Morris continues to stay active in research through his appointment as an intermittent assistant research scientist through the GEST, specializing in atmospheric modeling and satellite data analysis for trace gases, especially with respect to ozone in the troposphere and stratosphere.

This fall, he will return to Valparaiso as an assistant professor of physics and astronomy. Dr. Morris is author or co-author on nine peer-reviewed publications, and has been awarded numerous grant proposals to investigate issues in physics education research and to examine questions in Earth system science. In addition to his work on Match (as described in his technical report in this volume), Dr. Morris has become interested in issues of air quality, particularly as they relate to the Houston metropolitan area.

Dr. Rosana Nieto-Ferreira received a B.S. degree in meteorology in 1985, and an M.S. in meteorology in 1988, from the University of São Paulo, Brazil. She received a Ph.D. in atmospheric science from Colorado State University in 1994. From 1994 to 1996, Dr. Nieto-Ferreira was a postdoctoral fellow at Colorado State University, studying the role of tropical cyclones in the formation of tropical upper-tropospheric troughs. From 1996 to 2000, she was a Universities Space Research Association (USRA) visiting scientist at GSFC, working with the NASA Seasonal-to-Interannual Prediction Project (NSIPP) on the application of a variable-resolution version of the NSIPP-1 general circulation model to the study of seasonal-to-interannual variability of the land-atmosphere system in the Amazon Basin. Dr. Nieto-Ferreira has been a member of the research faculty at GEST since October 2000, working with the NSIPP on studies of variability and predictability of South American circulation and convection organization on timescales that vary from synoptic to multidecadal.

Dr. Wenge Ni-Meister received her B.S. degree in meteorology from China, a M.S. in micrometeorology at the University of Connecticut, and a Ph.D. in remote sensing and surface hydrology at Boston University. At the University of Maryland she worked as a postdoctoral student on land surface process modeling and forcing, and on validating a land surface process model with remote sensing data. She joined GEST and the Hydrological Sciences Branch at GSFC in July 2001, working on land data assimilation for NASA's Seasonal-to-Interannual Prediction Project (NSIPP). She also works on another project, studying the effects of subgrid snow-cover variability in vegetated regions on land-atmosphere interactions.

Dr. Mohan Nirala received his B.Eng. degree in civil engineering in 1987 from the Guru Ghasidas University, Bilaspur, India, and his M. Tech. in civil engineering (with a specialization in remote sensing) in 1991 from the Indian Institute of Technology (IIT), Bombay, India. Following the completion of his master's degree, Dr. Nirala joined the University of Bombay as lecturer, and taught courses in civil engineering and remote sensing for over two years. He also worked as a senior civil engineer on several projects in Bombay. In 1996, Dr. Nirala joined the Department of Applied Physics, Electronics, and Mechanical Engineering at the University of Dundee, Scotland, where he completed his Ph.D. in remote sensing in 1999. Immediately after completing his Ph.D., Dr. Nirala joined the University of Illinois at Urbana-Champaign as a postdoctoral research associate. His research focused on cloud detection and classification algorithms using Multiangle Imaging Scanning Radiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data. Following that appointment, he was awarded a postdoctoral research associateship by the National Academies of Sciences (NAS)/National Research Council (NRC) at GSFC in 2002. His research included multisatellite precipitation estimation and assimilation using microwave and other data products. Dr. Nirala was appointed an assistant research scientist in GEST in May 2003. His current research interests include validation techniques for land surface products and algorithms for the Visible and Infrared Imaging Radiometer Suite (VIIRS), to fly on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP). Dr. Nirala is a member of the American Geophysical Union.

Dr. Peter M. Norris received B.S. and M.S. degrees from the University of Auckland, New Zealand, in 1986 and 1989, respectively, and a Ph.D. in oceanography in 1996 from the Scripps Institution of Oceanography (SIO), University of California, San Diego, where his major research interest was numerical modeling of the stratocumulus-topped marine boundary layer. He continued this research in 1996 as a research oceanographer in the Marine Meteorology Research Group at SIO, and in 1997-1998

accepted a New Zealand Science and Technology Postdoctoral Fellowship at the National Institute for Water and Atmospheric Research in New Zealand, where he worked on marine boundary-layer modeling. In 1999, he joined the GSFC Center for Excellence in Space Data and Information Science (CESDIS) as a staff scientist, working on cloud parameterization behavior in a high-resolution global belt version of National Centers for Environmental Prediction (NCEP)'s Eta model. In 2000 he joined GEST as an assistant research scientist, working at the GSFC Data Assimilation Office (DAO) on cloud modeling and assimilation. During his career, Dr. Norris designed and conducted the first fully-Lagrangian, large-eddy simulations of the cloud-topped marine boundary layer. He also participated in numerous atmospheric field experiments, including the FIRE Cirrus II (Kansas, 1991), FIRE ASTEX (Azores, 1992), TOGA-COARE (Solomon Islands, 1993), and CRYSTAL-FACE (Florida, 2002), with roles in data collection, aircraft flight direction, and data analysis.

Dr. Bob Numrich received his B.S. degree in chemistry from the University of Illinois, Urbana, and his Ph.D. in theoretical chemistry from the University of Minnesota, Minneapolis. He began his career in supercomputing when he joined Control Data as part of the STAR-100 (and later the Cyber-205) consulting group. He was a leader in the development of vector code for these early vector architectures. He joined Cray Research as part of the Cray-2 development group, where he continued work on vector codes and began work on parallel codes for the four-processor Cray-2. He also performed extensive analysis of interprocessor memory contention for the Cray-2 and developed simulators and models to describe memory contention. He continued that work on the Cray-3 until that project left Cray Research. Dr. Numrich was a member of the core team that developed Cray's first massively parallel processor, the Cray-T3-D. He invented the get/put model for one-sided message passing which became the Shmem Library still in use today and supported on several different systems. The Shmem Library became the model for MPI-2 one-sided communication. Dr. Numrich also invented the F-minus-minus extension to Fortran, which expressed the one-sided model as an extension to the language. He has extended that model to include all of Fortran 95 under the new name of Co-Array Fortran (CAF). His language extension is considered a prime candidate for programming the next generation of parallel machines because of its simplicity and its potential for scaling to large numbers of processors. Dr. Numrich is currently a senior research associate at the Minnesota Supercomputing Institute, University of Minnesota, Minneapolis. He is developing object-based parallel libraries that combine the object-oriented features of Fortran 95 with co-array syntax. He is also involved in performance modeling, defining a system of units for performance measurement, and developing computational metrics based on the principle of least action.

Dr. Mark A. Olsen received a B.S. degree in physics from the University of Northern Iowa in 1993 and a Ph.D. in physics from Iowa State University in 2000. His doctoral research examined near-tropopause dynamics and structure of baroclinic systems from total column ozone data and mesoscale model analyses. From 2000 to 2002, he held a National Research Council postdoctoral fellowship at GSFC, where his work concentrated on midlatitude stratosphere-troposphere exchange of ozone and mass. Dr. Olsen became a research associate at GEST in December 2002, studying the exchange of air and chemical species across the tropopause. His research focuses on the analysis of stratospheric-tropospheric exchange in global atmospheric data sets and model output.

Dr. Kevin Olson received his Ph.D. from the University of Massachusetts in 1990. For his novel use of a supercomputer, he received first place in the IBM 3090 supercomputing competition, sponsored by IBM Corporation. After receiving his doctorate, he began work at GSFC as part of the in-house team of scientists for the High-Performance Computing Project. During this time, his research focused on developing numerical algorithms for scientific purposes using high-performance parallel computers. One of the main achievements during this period was participation in the development of a software package known as PARAMESH. PARAMESH was developed to allow a user to more easily add dynamic adaptive mesh refinement to an existing application and to make use of parallel computer architectures.

Dr. Olson has also worked at the University of Chicago as part of the Department of Energy's Advanced Strategic Computing Initiative (ASCI). The code that was developed using the PARAMESH software at the University of Chicago recently won a Gordon Bell Prize for performance. Dr. Olson continues to work on developing and extending PARAMESH, and collaborating with people in different scientific communities to develop codes that use PARAMESH.

Dr. Norm O'Neill is a physicist who received his Ph.D. in space science from York University (Toronto) in 1982. After four years as a project scientist with a private remote sensing company (Moniteq, Ltd.), he joined the remote sensing faculty of the Université de Sherbrooke where he is currently a full professor. His research centers on analysis of aerosol optical data acquired by ground-based, airborne, and satellite sensors. A significant portion of his research activities has focused on collaborative projects with the classical remote sensing community, where the goal was atmospheric correction of airborne and satellite imagery. From 1997 to 2000, Dr. O'Neill was editor-in-chief of the *Canadian Journal of Remote Sensing,* and from 1996 to 1998, he was director of the doctoral program in remote sensing at the Université de Sherbrooke. Awards and honorific positions have included a National Sciences and Engineering Research Council (Canada) (NSERC) postdoctoral fellowship, a Fonds pour la Formation de Chercheurs et l'Aide Recherche (FCAR) tenure-track fellowship, and a National Research Council (NRC) senior associateship.

Dr. Judit M. Pap received her Ph.D. in astrophysics in 1986, from Eötvös University, Budapest, Hungary, where she worked as a research associate until 1988 when she became a visiting scientist at the Institute for Solar Physics in Freiburg, Germany. She was appointed research associate at the University of Colorado at Boulder in 1989. She was a staff member of the Jet Propulsion Laboratory between 1991 and 1997, and research astronomer at the Department of Physics and Astronomy at UCLA until the end of November 2001. Dr. Pap has been a senior research scientist at GEST since June 2001. She conducts research on solar irradiance variations and their effect on the Earth's atmosphere and climate, using ground- and space-based measurements. She is a NASA-funded co-investigator on the ESA/NASA SOHO/VIRGO and MDI experiments, guest investigator on the UARS mission, and co-investigator on the French PICARD experiment. She is principal investigator on various grants from NASA's Office of Space and Earth Sciences. Dr. Pap is involved in a wide range of collaborations with scientists from JPL, UCLA, USC, NRL, SSAI, the University of Hawaii, the University of Arizona, NCAR/HAO, NOAA/SEC, CNRS, (Paris, France), PMOD/WRC (Davos, Switzerland), and the Heliospheric Observatory (Debrecen, Hungary). Dr. Pap has organized several international meetings on solar irradiance variations, and chaired the last workshop of Working Group 1 of the International Solar Cycle Studies, working under the auspices of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). She has been elected as chair of the Working Group 1 "Solar Variability" of Theme 4 "Space Climatology" of the newly implemented program of SCOSTEP, "Climate And Weather of the Sun-Earth System" (CAWSES). CAWSES will collaborate with the International Living With a Star (ILWS) program, which will play a major role in solar-terrestrial physics in the next decade and beyond. Dr. Pap has also been the chief editor of AGU Monograph Series No. 141: *Solar Variability and Its Effect on Earth's Climate,* published in March 2004.

Dr. Steven Pawson completed his education in the United Kingdom. He received a B.Sc. degree in mathematics from the University of York (1982), a master's degree in atmospheric physics and dynamics from Imperial College, University of London (1984), and a Ph.D. in meteorology from the University of Edinburgh (1987). His dissertation examined aspects of the radiation balance and trace-gas transport in the middle atmosphere using data from the NIMBUS-7 LIMS instrument. Following a one-year position as a research fellow at the University of Oxford, Dr. Pawson moved to the Free University of Berlin in 1988. In both positions, he worked on the development of middle-atmosphere climate models. In Berlin, he became a junior faculty member in 1991, teaching and performing research on the middle atmosphere and climate. He was awarded the Habilitation in 1997. Later that year, he accepted a visiting scientist position with the Universities Space Research Association, based in the Atmospheric Chemistry and

Dynamics Branch at GSFC. In 1998, he joined the Data Assimilation Office (DAO). He was appointed as a senior research scientist at GEST in December 2000. He is presently the lead scientist for trace constituents in the Global Modeling and Assimilation Office at GSFC. He has published over 40 refereed journal articles, leads an international model validation program, and has served on numerous national and international committees. He is presently editor of the *Journal of Geophysical Research – Atmospheres*.

Dr. Zhaoxia Pu received a Ph.D in atmospheric sciences in 1997 from Lanzhou University, soon after she completed the necessary research at the National Centers for Environmental Prediction (NCEP)/ National Oceanic and Atmospheric Administration (NOAA), Camp Springs, Maryland during 1993-1996. She continued her research at NCEP as a University Corporation for Atmospheric Research (UCAR)/NCEP postdoctoral fellow in 1997-1998. During her five years at NCEP, Dr. Pu joined several NCEP research efforts to improve the NCEP global data assimilation system. She also made significant contribution to developing the NCEP targeting weather observation techniques. In November of 1998, Dr. Pu joined the Universities Space Research Association and worked at GSFC for two years before transferring to GEST as an associate research scientist in October 2000. Dr. Pu's research focuses on atmospheric and oceanographic data assimilation. Her current research emphasizes the application of data assimilation in mesoscale studies of tropical cyclones and mesoscale convective systems. Dr. Pu has published over 10 refereed papers in leading professional journals; she also serves as a reviewer for professional journals. In December 2000, Dr. Pu received an Outstanding Achievement Award from the Mesoscale Atmospheric Processes Branch, Laboratory for Atmosphere, GSFC.

Dr. Udaya A. Ranawake received a B.S. degree in electrical engineering from the University of Moratuwa, Sri Lanka, and M.S. and Ph.D. degrees in electrical and computer engineering from Oregon State University, Corvallis, Oregon. Prior to joining GEST, he worked for four years at Center for Excellence in Space Data and Information Science (CESDIS) on a subcontract with the Department of Computer Science and Electrical Engineering at the University of Maryland, Baltimore County. From 1992 to 1995, Dr. Ranawake was a senior member of the technical staff at Hughes STX Corporation, where he was the task leader for massively parallel research at GSFC. He has been at GEST since July 2000. His research interests are algorithms for scientific computation, parallel and distributed computing, computer architecture, and computer networks. Dr. Ranawake is a member of the Institute of Electrical and Electronics Engineers (IEEE).

Dr. Miodrag Rančić received a Ph.D. in meteorology in 1988 from the University of Belgrade, Yugoslavia, where he worked as a research and teaching assistant, and from 1988 as an assistant professor. In 1989, Dr. Rančić joined the Center for Analysis and Prediction of Storms at the University of Oklahoma as a postdoctoral faculty member. Dr. Rančić worked at the National Centers for Environmental Prediction as a research scientist from 1992-1998, when he transferred to GSFC, employed through the University of Maryland, Baltimore County. In December 2003, Dr. Rančić became a research associate professor of physics at UMBC, through affiliation with the Joint Center for Earth Systems Technology (JCET). He joined GEST in July 2000. His research interest is the development of novel numerical methods for weather and climate prediction, in conjunction with modern software development trends, such as application of high-performance computing and object-oriented design. Dr. Rančić initiated and contributed to the development of a nonhydrostatic version of the major regional model of the U.S. Weather Service; he also originated a new class of mass conservative semi-Lagrangian schemes for application in numerical models of the atmosphere, and developed a new class of quasi-uniform grids (so-called conformal *cubic* and *octagonal* grids) for application to global atmospheric models. He has over 30 papers published in refereed professional journals or presented at workshops and conferences.

Dr. Oreste Reale received his laurea in geophysical engineering from the University of Trieste, Italy, in 1990. From 1990 to 1992, Dr. Reale worked on applied geophysics at the University of Trieste. From 1992 to 1996, he was a graduate student at the University of Maryland, College Park, where he received his Ph.D. in meteorology in 1996. Upon completing his doctorate, Dr. Reale worked from 1996 to 1999 as a visiting scientist at the International Center for Theoretical Physics (ICTP), Physics of Weather and Climate Section, Trieste. He also consulted for a weather forecasting operational center (CMIRL, Genoa, Italy) as an invited lecturer on synoptic-dynamic meteorology, and was co-advisor on three theses on synoptic meteorology at the University of Trieste. From 1999 to 2001, Dr. Reale moved to the Center for Ocean-Land-Atmosphere Studies, Institute for Global Environment and Society (COLA-IGES), Maryland, where he worked on the impact of land-surface evaporation variability and on the dynamics of Mediterranean floods. He joined GEST in July 2001 as an associate research scientist. Dr. Reale's current research focuses on the synoptic and dynamic meteorology of extreme events. In particular, he investigates the sensitivity of extreme events, such as explosively developing baroclinic cyclones, tropical cyclones, and extratropical subsynoptic scale cyclones, to different data types and different data assimilation procedures. In December 2002, Dr. Reale received the Outstanding Performance Award from the Data Assimilation Office (DAO) in the Laboratory of Atmospheres at GSFC.

Dr. Rolf H. Reichle received a B.S. degree in mathematics and a M.S. in physics from the University of Heidelberg, Germany in 1992 and 1996, respectively, and a Ph.D. in environmental engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA in 2002. His doctoral dissertation dealt with the optimal assimilation of remote sensing data for land surface hydrology applications. He worked for one year as a postdoctoral research associate at the Ralph M. Parsons Laboratory at MIT, where he continued and expanded his work on land data assimilation. In 2001, he joined GEST as a member of the research faculty. His main research interest is the seasonal prediction of climate variability; his goal is to support NASA's Seasonal-to-Interannual Prediction Project (NSIPP) with his experience in land data assimilation. His publications include papers on global soil moisture data, land data assimilation, and on groundwater contaminant transport.

Dr. Lars Peter Riishojgaard received a M.Sc. in geophysics from the University of Copenhagen in 1989 and a Ph.D. in geophysics from the same institution in 1992. His permanent affiliation from 1989 through 1995 was with the research department of the Danish Meteorological Institute in Copenhagen. Part of his dissertation work in general circulation modeling with special emphasis on processes relevant for stratospheric ozone was carried out at the Centre National de Recherches Météorologiques in Toulouse. He took up a visiting scientist position there from 1993-1994, a period during which he pioneered the application of variational assimilation methods to the problem of driving dynamical flow fields from tracer observations. Late in 1995, he came to the Data Assimilation Office (DAO) at GSFC as a Universities Space Research Association (USRA) visiting fellow. He designed and led the development of a three-dimensional ozone assimilation system, in parallel with carrying out research in the area of state-dependent covariance modeling. In June 1999, he took up a staff position at the European Meteorological Satellite (EUMETSAT) organization in Darmstadt to address user requirements for future space-based observing systems as his main responsibility. In August 2000, he returned to the DAO to lead the development of its analysis system, and with the formation of the GMAO in 2003 he became the lead of its satellite data group. Dr. Riishojgaard has been with GEST since September 2000 as a senior research scientist. He has been deputy director of the NASA/NOAA Joint Center for Satellite Data Assimilation since August 2002. In July 2003 he was appointed head of the Satellite Data Group in the Global Modeling and Assimilation Office (GMAO) at GSFC, with responsibility for coordinating NASA's global satellite data assimilation activities, including activities related to new and prospective data types.

Dr. Joan E. Rosenfield joined GEST in April 2001 as a senior research scientist. Dr. Rosenfield received an A.B. degree, with a major in chemistry, from Brandeis University in 1961, and a Ph.D. in physical

chemistry from the University of Minnesota in 1969. She conducted research into the use of optical rotary dispersion as an aid in elucidating the electronic structure of molecules at the University of Minnesota from 1969 to 1972. She continued this research at the National Institutes of Health's Laboratory of Chemical Physics from 1973 to 1977. In 1977, Dr. Rosenfield joined the GSFC Modeling and Simulation Facility, where she worked on remote sensing of weather and climate parameters from satellite data. Since 1982, she has worked in the Atmospheric Chemistry and Dynamics Branch at GSFC. There, she developed a radiative transfer model used to compute radiative heating rates in the stratosphere and troposphere. She has worked on modeling the radiative, dynamical, and chemical state of the stratosphere, with emphasis on understanding the stratospheric ozone layer. Dr. Rosenfield's recent publications have dealt with radiative/dynamical processes in the stratospheric polar vortex, the radiative effects of aerosols, and the effects of increasing greenhouse gases on stratospheric trace species.

Dr. Susan E. H. Sakimoto received a B.A. in geology from Whitman College in 1989, a M.A. in earth and planetary sciences from Johns Hopkins University in 1991, and a Ph.D. in earth and planetary sciences (geophysics) also from Johns Hopkins University, in 1995. Her research career has to-date included theoretical, computational, and mission-related research on Venusian magma ascent and volcanism, Martian lava flow topography and emplacement, and Martian volcanic edifices and impact crater topography, using measurements from the Viking, Magellan, and Mars Global Surveyor data sets. Her most recent work is in the physical volcanology of lava channels, combining analytic, experimental, and computational work, and in the topography and emplacement of Martian impact craters, basins, and small volcanic features. This includes extensive work with Mars Orbiter Laser Altimeter (MOLA) topography, performed in collaboration with the MOLA science team. At GSFC she has been a NASA graduate student research fellow (1990-1994), a NRC resident research associate (1995-1997), and a Universities Space Research Association (USRA) visiting scientist (1997-2000). She is currently an associate research scientist at GEST. She has also been an instructor in earth and space sciences since 1998 at the Johns Hopkins School of Professional Studies in Business and Education, she teaches in their Master's of Science in Education Program and Earth Sciences Secondary Teacher Certification Program.

Dr. Robert Schiffer is the chief scientist for GEST. Dr. Schiffer received his Ph.D. in 1971 from the University of California at Los Angeles in meteorology. He has over 27 years of program management experience at NASA HQ, including positions as deputy director of the Research Division, chief of the Atmospheric Science Branch, chief of the Climate and Hydrologic Systems Branch, and manager of NASA's Climate Research Program and Global Atmospheric Research Program. He has chaired or cochaired numerous national and international research panels in the areas of climate studies. These activities included directorship of the WMO's World Climate Research Program - Radiation Project Office, and directorship of the U.S. Secretariat for International Global Observing Systems Programs. Dr. Schiffer also worked for 11 years at the Jet Propulsion Labs as a research engineer/scientist, involved in NASA's Planetary Exploration Program. His most recent accolade was the award of the NASA Distinguished Service Medal after he retired last year from GSFC.

Dr. Adam Schlosser received his B.S. in physics from the University of Massachusetts, in 1989. He earned his M.S. and Ph.D. in meteorology from the University of Maryland, College Park in 1992 and 1995, respectively, having performed studies in land surface hydrology. He was a UCAR visiting scientist at Geophysical Fluid Dynamics Laboratory, Princeton University from 1995-1997, and a research scientist at the Center for Ocean-Land-Atmosphere Studies (COLA), Calverton, MD from 1997-2001. Since that time, he has been an associate research scientist at GEST, with the role of project scientist in NASA's Global Water and Energy Cycle Project Office.

Dr. Sonia Seneviratne completed most of her education in Switzerland. She first studied biology at the University of Lausanne (B.Sc./"Attestation de Prélicence", 1995) and environmental physics at the Swiss Federal Institute of Technology (ETH) in Zurich (M.Sc./"ETH-Diplom", 1999). She performed her M.Sc.

thesis work at the Ralph M. Parsons Laboratory for Hydrodynamics at the Massachusetts Institute of Technology (MIT), Cambridge, MA, under the guidance of Professor Elfatih Eltahir (October 1998-April 1999). Following this stay, she conducted her Ph.D. dissertation work at the ETH Zurich (1999-2002), under the guidance of Professor Christoph Schär. Her coexaminors were Dr. Pedro Viterbo (European Centers for Medium Range Weather Forecasts, ECMWF) and Prof. Wolfgang Kinzelbach (ETH Zurich). Her dissertation examined terrestrial water storage in the context of land-atmosphere interactions and climate change, and investigated a new approach for estimating changes in terrestrial water storage from water-balance computations. Dr. Seneviratne was awarded a postdoctoral fellowship from the National Center of Competence in Research on Climate (NCCR-Climate) from Switzerland based on this work. She is presently a visiting research associate at GEST and GSFC, where she works in collaboration with Dr. Randy Koster.

Dr. Chung-Lin Shie, originally from Taiwan, R.O.C., received a B.S. degree in atmospheric sciences from National Taiwan University in 1977. He was curious about snowy weather and ended up with a M.S. in meteorology from Pennsylvania State University in 1985. Missing the sunshine, led him to Florida State University, where he received his Ph.D. in meteorology in 1995. Then, he returned to the cold D.C. Metropolitan area and became a research meteorologist at NASA/GSFC affiliated first with SSAI (till March 2001). He has been with UMBC/GEST since April 2001 as an associate research scientist. During his early career (from February 1993 to March 1997), he had mainly worked on the development and improvement of an Empirical Orthogonal Functions (EOF) model for surface humidity retrieval over the global oceans using the Special Sensor Microwave Imager (SSM/I) precipitable water data. He later produced a global (2x2.5 grid) daily air-sea surface flux product for a 7.5-year period (from July 1987 to December 1994), which was archived and distributed by the GSFC distributed active archive center (DAAC). Since April 1997, he joined his current research project involving numerical simulations using 2- and 3-dimensional GSFC Cumulus Ensemble (GCE) models, and scientific analysis to study radiative-convective systems and their interactions with large-scale environment. In 2000, he won an "Annual Outstanding Performance Award" of Mesoscale Atmospheric Processes Branch, NASA/GSFC. He later won an "Outstanding Mentoring Award" from UMBC/GEST in 2003. While working as a full-time researcher in science, he however considers himself a 50% research meteorologist (cloud modeling, air-sea interaction, remote sensing, and atmospheric dynamics), 20% arts-lover, 20% philosophy-seeker, and 10% math-hobbyist. He had moonlighted as an amateur Chinese Calligraphy teacher during his leisure time for several years (from 1995 to 2001).

Dr. Alexander Siniuk received his B.S. and M.S. degrees in physics and theoretical physics from Belarus State University in 1985, and a Ph.D. in physics/optics in 1997 from the Institute of Physics, Minsk, Belarus. Beginning in 1998, he was a research associate in the Laboratory of Optics of Disperse Medium at the Institute of Physics. Later that year, he became a visiting scientist at the Laboratory of Meteorological Physics, Université Blaise Pascal, France, and became a visiting scientist at the Meteorological Research Institute, Tsukuba, Japan in 1999. Dr. Siniuk was an assistant research scientist at GEST before joining SSAI in 2004. His research interests include satellite remote sensing with emphasis on developing inversion methods for retrieval of aerosol properties.

Dr. Alexander Smirnov received a M.S. in physics from St. Petersburg State University, St. Petersburg, Russia in 1980 and a Ph.D. in oceanology (physics and mathematics) in 1988 from the Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia, where his major research interest was the optical properties of atmospheric aerosol over the oceans. From 1980 to 1991, Dr. Smirnov served as a scientist and senior scientist at St. Petersburg Hydrometeorological Institute, developing aerosol models and participating in marine and coastal expeditions. From 1993 to 1996, he was a postdoctoral fellow and project scientist at the Université de Sherbrooke, Sherbrooke, Québec, Canada, where he successfully studied the effect of various synoptic air masses on the atmospheric optical parameters. In June 1996, Dr. Smirnov joined Science Systems and Applications, Inc., and started work on the Aerosol Robotic

Network (AERONET) Project. He has led and contributed to the design and implementation of the operational cloud screening and quality control algorithm for the AERONET database. His current research interests include shipborne and ground-based studies of atmospheric aerosols, remote sensing instrumentation, and data analysis. Dr. Smirnov has been with GEST since October 2001. He has over 50 peer-reviewed papers in leading geophysical journals. He is presently one of three co-investigators on the AERONET project.

Mr. Gregory Solyar received a B.S. degree in radio metrology from Odessa Measuring College of Standards Committee of the USSR in 1981, a M.S. in electrical engineering from Odessa State Polytechnic Institute in 1986, and a M.S. in electrical and computer engineering from the Johns Hopkins University in 1998, where his major interest was in nonlinear optics and quantum electronics. He is currently working toward a Ph.D. in the Department of Computer Science and Electrical Engineering at UMBC, where his research interest is in imaging methods and algorithms. In December 2000, he joined Center for Excellence in Space Data and Information Science (CESDIS) and became an associate research scientist at GEST in June 2000. Mr. Solyar has over 15 years of experience in industry and research institutions. During his professional career as a group head at Central Communications Design Bureau, he designed metrology, algorithms, and microprocessor embedded hardware and software for control and measurement equipment for communications lines (1986-1990). At Johns Hopkins University, he designed and experimented with an optical parametric oscillator, passive Q-switched lasers, and laser diodes (1997-1999). At the National Institutes of Health, he researched special surface effects in photomultiplier tubes, and designed, implemented, and tested systems with fast, small detectors for small fluorescent power emission (1997-1998). As a scientist at GEST he specializes in wave-front sensing methods, techniques, and algorithms, including phase-diversity and interferometry.

Dr. Harold Stone received a B.S. degree in electrical engineering from Princeton University (1960), and an M.S. and Ph.D. in electrical engineering from the University of California, Berkeley in 1961 and 1963, respectively. His research activities include extensive work in computer architecture and satellite image processing. He is known for his contributions to the interconnections for parallel computers through his research on the perfect-shuffle interconnection pattern. Dr. Stone has held faculty positions at Stanford University and the University of Massachusetts, and research positions at IBM and NEC. He retired from NEC in 2001, and holds the title of Fellow, Emeritus. He is the author or coauthor of eight textbooks in the areas of computer science and electrical engineering. He has served on the governing board of the Institute of Electrical and Electronics Engineers (IEEE) Computer Society, and was a vice president of that organization Dr. Stone works for GEST as an external consultant to Dr. Jacqueline LeMoigne at GSFC to study image registration and fusion for future formation flying systems with a goal of implementing these registration schemes on high-performance parallel computers that could be carried on spacecraft.

Dr. Susan Strahan received a B.S. degree in chemistry from Stanford University in 1980, and a Ph.D. in chemistry from the University of California, Berkeley in 1986. She was a National Research Council (NRC) postdoctoral fellow at the NASA Ames Research Center, where her research involved making stratospheric trace gas measurements with an airborne spectrometer on the NASA ER-2 aircraft. As a visiting scientist at the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Lab (GFDL) from 1990-1992, she continued the analysis of those measurements, using the results to evaluate the stratospheric circulation of the GFDL ‘SKYHI’ model. Since 1992, she has been at GSFC, and presently works in the Atmospheric Chemistry and Dynamics Branch. Her research involves analysis of trace gas measurements from aircraft and satellite platforms. The observational analyses are used to develop diagnostics that evaluate the credibility of atmospheric models. She contributes to the evaluation of the GSFC Chemistry and Transport Model and the NASA GMI models. At present, she is the project manager for the Global Modeling Initiative, overseeing model evaluation and coordinating production of new model simulations.

Dr. Chaojiao Sun received a B.S. degree from the University of Science and Technology of China (USTC) and a Ph.D. in oceanography from Oregon State University, where her major research interest was internal waves and turbulent mixing in the upper-equatorial oceans. In 1998, she joined UCLA at the Department of Atmospheric Sciences and the Institute of Geophysics and Planetary Physics. She carried out research on data assimilation with an intermediate coupled ocean-atmosphere model to study the El Niño/Southern Oscillation (ENSO) using a sequential estimator—the extended Kalman filter. She joined GEST in November 2000, and has been working on snow data assimilation with land surface models, and ocean data assimilation with general ocean circulation models. Her major research interests are ocean data assimilation, coupled model assimilation, the ENSO, tropical oceanography, and snow data assimilation.

Dr. Lin Tian received a Ph.D. in atmospheric science from the University of Chicago in 1995. Her major research interest was radar meteorology and cloud microphysics. In 1997, she joined the Universities Space Research Association and worked at GSFC. In October 2000, she joined the GEST as an associate research scientist, working on cloud modeling. Over the past three years she has conducted research in areas related to remote measurement of precipitation, understanding storm structures, and microphysical characteristics of precipitation, using observations from the ER-2 airborne Doppler radar (EDOP). She has analyzed EDOP data in support of Tropical Rainfall Measuring Mission (TRMM) to improve rainfall rate estimates. She also studied the microphysics of storms (such as raindrop size distribution and melting ice particles) using EDOP and ground-based polarimetric radar data. In addition to her scientific research, she has gained tremendous experience in EDOP data collection, processing, and software development. Dr. Tian participated in three TRMM field campaigns and the Cirrus Regional Study of Tropical Anvils and Cirrus Layers –Florida Area Cirrus Experiment (CRYSTAL-FACE) experiment, and processed all EDOP and Cloud Radar System (CRS) data for archiving and distribution.

Dr. Yudong Tian received a Ph.D. in atmospheric sciences in 1999 from UCLA, where he conducted research in climate dynamics and geophysical fluid dynamics. He was one of the developers of the popular advanced spectral analysis SSA-MTM Toolkit. Prior to joining GEST, he had worked in Internet-related industry, holding positions as systems manager and chief technology officer. In addition to his atmospheric research background, Dr. Tian has extensive professional experience in network architecture, software engineering, database design, and system and network security. He has been working on GSFC's Land Information System since early 2002, building a high-performance computing platform for real-time land surface simulation and data assimilation.

Mr. Jonathan M. Triggs is a research coordinator for GEST, conducting his research at GSFC. Mr. Triggs earned a B.S. degree in geography in 1998 at Arizona State University (ASU). After obtaining his first degree, he began working for the University of Arizona Maricopa Agricultural Center at the U.S. Water Conservation Lab (USWCL, USDA/Agricultural Research Service) in Phoenix, Arizona. Shortly thereafter, he returned to ASU, completing a M.A. in geography in 2002. At the USWCL, he worked with a team of researchers studying the effects of increased carbon dioxide on agricultural crops. His research focused on evapotranspiration and water resources. Today, he works with the Hydrological Sciences Branch at GSFC to understand land-atmosphere interactions, particularly with respect to water resources management and decision support systems.

Dr. Sushel Unninayar is presently a senior research scientist at GEST. He received a B. Tech. (honors) in IIT and electrical engineering from I.E.E, London, in 1968, a M.S in electrical engineering in 1971 from the University of Hawaii, and his Ph.D. in meteorology in 1978 from the Institute of Geophysics, University of Hawaii. He was deputy director of International GARP programs and interdisciplinary, international field campaigns/projects such as MONEX, the International Monsoon Experiment, and ALPEX, the International Alpine Mountain Experiment, in 1978-1981. He was division head for the World Climate Program (WCP) of the World Meteorological Organization, from 1981-1987. Dr. Unninayar was senior scientific advisor, seconded by NASA-HQ, to the UN Environment Program

(UNEP) in 1987-1988, and a program director at NSF for Global Change Research Planning from 1988-1991. He has been with NASA-HQ/ESE in various senior scientist capacities since 1991. He directed the NASA HQ Greenhouse Effect Detection project from 1991-1993, and was seconded by NASA HQ to the UN Institute for Training and Research in 1993-1994 as director of International Projects to address global change and climate change research. Dr. Unninayar was director of the U.S. vice-presidential initiative of the GLOBE Project at UCAR/NCAR from 1994-1995, and has been directly involved and instrumental, from its inception, in the planning and implementation of the World Climate Research program, the U.S. Global Change Research program, and the U.S. Climate Change Science program.

Dr. Igor Veselovskii graduated from the faculty of theoretical and experimental physics of the Moscow Engineering Physical Institute in 1982. In 1987, he received his Ph.D. from the same institute for studies in photoacoustics. Beginning in 1988, he worked at the Physics Instrumentation Center of the General Physics Institute. From 1988-1994 he was involved in the developing excimer lasers and in nonlinear optics studies, such as phase conjugation, Raman conversion, and Brillouin compression of ultraviolet (UV) laser pulses. In 1995, he became the head of the lidar program. He spent one year as a visiting researcher in South Korea (KAERI), and one year in Brazil (INPE). Since 2001, he has worked with GSFC. His current scientific interests include development of lidars for tropospheric ozone monitoring, Raman lidars for the water vapor and liquid water studies, and multiwavelength lidars for aerosol size distribution retrieval.

Dr. Augustin Vintzileos received his PhD. In 1996 from the Université de Paris V, with research conducted at the Laboratoire de Météorologie Dynamique of the CNRS. His subject was the study of climate variability with a global atmosphere-tropical Pacific Ocean coupled model. He also has a DEA. (M.Sc. level) from the same institution, awarded in 1991, and received a M.Sc. in 1990 in computational fluid dynamics from the Imperial College of Science and Technology at the University of London. After holding a position as visiting scientist at the Universities Space Research Association from 1999-2000, he joined GEST, first as a visiting scientist, then as an assistant research scientist participating in NASA'S Seasonal-to-Interannual Prediction Project (NSIPP).

Dr. Hailan Wang received a B.S. degree in marine meteorology in 1994 from the Ocean University of Qingdao in the People's Republic of China. She then pursued graduate study at the University of Illinois at Urbana-Champaign, and obtained her M.S. and Ph.D. degrees in atmospheric sciences in 1997 and 2000, respectively. In the fall of 2000, she moved to Princeton, NJ and worked in the Climate Diagnostic Group in the Geophysical Fluid Dynamics Lab (GFDL) as a postdoctoral visiting scientist. In December 2002, she joined the Climate and Radiation Branch of GSFC, under the auspices of GEST. A past major research effort has been on understanding global and regional climate and their variations from a stationary wave perspective, using diagnostic linear and nonlinear stationary wave modeling approaches. She has also been engaged in a number of other research topics, including the impact of air-sea interaction, *e.g.,* El Niño/Southern Oscillation (ENSO), on climate variation in local and remote regions, and the response of tropical climate to global warming in coupled model simulations. During her stay at GEST, she is investigating the potential importance of extratropical air-sea interaction on the predictability of variations in U.S. summertime precipitation.

Dr. Jian-Jian Wang received a B.S. degree in Meteorology in 1987 from Peking University, China, a M.S. degree in meteorology in 1990, and a Ph.D. degree in meteorology in 1995 from the University of Hawaii. Dr. Wang specializes in tropical meteorology, mesoscale meteorology, and radar meteorology. His research and publications have focused on the structure and evolution of mesoscale precipitation systems and the interaction between the systems with different scales in the tropics. He has held positions as a research assistant at the University of Hawaii (1990-1995) and Peking University (1987-1990). In 1995, Dr. Wang was awarded funding by University Corporation of Atmospheric Research (UCAR) for a two-year postdoctoral fellowship working on National Centers for Environmental Prediction (NCEP)'s

regional spectral model (RSM) to improve numerical forecasts in the Pacific Region. Between 1997 and 1999, he was a postdoctoral research associate with the University of Illinois and National Center for Atmospheric Research (NCAR). His research during that period led to a better understanding of the thermal and dynamic effects of local topography on large-scale airflow. During the last ten years, he has worked extensively with a broad spectrum of instrumentation including conventional and dual-Doppler radars, rawinsonde soundings, Portable Automated Mesonet (PAM) stations, and aircraft and satellite data. His observational studies have focused on the syntheses of physical processes revealed by different data sources from mesoscale field experiments (*e.g.*, the Hawaiian Rainband Project, SCS Monsoon Experiment, SCSMEX). Dr. Wang was an assistant research scientist in JCET beginning in February 1999, and transferred to GEST in February 2002.

Dr. Yujie Wang received B.S. and M.S. degrees in physics from Tsinghua University, Beijing, China in 1994 and 1998, respectively, and a Ph.D. in geography from Boston University, Boston, MA in 2002. In July 2002, Dr. Wang joined GEST as a research associate. During his Ph.D. work, Dr. Wang's research focused primarily on prototyping and validating the radiative transfer-based Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) leaf area index (LAI)/fraction of photosynthetically active radiation (FPAR) algorithm. At present, he is developing a new, generic aerosol retrieval and atmospheric correction algorithm for the EOS Multiangle Imaging Scanning Radiometer (MISR), MODIS, and the future National Polar-orbiting Operational Environmental Satellite System (NPOESS) Visible Infrared Imager Radiometer Suite (VIIRS) instruments.

Dr. Zhien Wang is currently an assistant research Scientist at GEST. Dr. Wang received a B.S. degree in physics in 1990 from Anhui Normal University, China; a M.S. in atmospheric optics in 1994 from the Anhui Institute of Optics and Fine Mechanics, China**;** and a Ph.D. in meteorology from the University of Utah in 2000. He conducted research in remote sensing of atmospheric aerosol and ozone at the Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences from 1990-1996, and won national research awards for building the first ozone lidar in China. Before joining GEST in February 2002, he worked at the University of Utah as a postdoctoral research associate and assistant research professor, and conducted research in cloud property retrievals by combining multiple remote active and passive sensors. Together with Dr. David Whiteman at GSFC and Dr. Kenneth Sassen of the University of Alaska, he works on Earth Observing System (EOS) Aqua validation and CloudSat algorithm development. He is also a member of the Atmospheric Radiation Measurement (ARM) science team to improve the experimental cloud classification algorithm into an operational algorithm and to develop new algorithms to study mixed-phase cloud microphysical properties.

Dr. Clark Weaver's scientific initiation was at the Ohio State University at the Byrd Polar Research Institute. His master's thesis topic was the fractionation of isotopic oxygen in snow over Antarctica. He received his Ph.D. in atmospheric science from Colorado State University in 1987. His dissertation was on the mechanism of marine stratocumulus break up. He next joined the research group at the Graduate School of Oceanography at University of Rhode Island, and studied the transport of mineral dust to ocean drilling sites using paleoclimate models. He joined the Atmospheric Chemistry and Dynamics Branch at GSFC in 1991, and has worked there ever since. His current interests include stratospheric transport, data assimilation, and remote sensing.

Dr. Guoyong Wen received a B.S. degree from Peking University in 1982, a M.S. in atmospheric sciences in 1987 from Purdue University, and a Ph.D. in atmospheric physics in 1992 from the University of Chicago. He did his postdoctoral work at Argonne National Laboratory. His research interests focus on atmospheric remote sensing, ozone, aerosols, clouds, and atmospheric radiative transfer, climate variations, solar variability. He joined GEST in 2003.

Professor Kathy Whaler received her Ph.D. in 1981 from Cambridge University, UK. After two additional years as a postdoctoral researcher, she moved to a faculty position at University of Leeds, UK. In 1994, she moved to University of Edinburgh to become the chair of the Department of Geophysics, and was department head from 1999-2002. Professor Whaler is a Fellow of the Royal Society of Edinburgh and the Institute of Physics. She has been a visiting scientist at Harvard University, GSFC, Scripps Institution of Oceanography, Victoria University of Wellington, New Zealand, and the Institut fur Geophysik in Göttingen, Germany. She has held a Fulbright Travel Scholarship, been a Cecil and Ida Green Scholar, and a Gauss Professor of the Göttingen Academy of Sciences. Most recently, she has been a visiting senior research scientist at GEST. Professor Whaler's research interests address planetary magnetism, including satellite magnetic field data modeling, geophysical inverse theory, core dynamics and thermal history, magnetotellurics, mantle electrical conductivity, and potential field theory.

Dr. Liguang Wu is an assistant research scientist at GEST. He received a B.S. degree in meteorology from Nanjing University, China, in 1984, a M.S. in meteorology from the State Oceanic Administration (SOA), Beijing, China, in 1990, and a Ph.D. in meteorology from the University of Hawaii in 1999. Dr. Wu served as an operational weather forecaster at SOA from 1984 to 1987 and from 1990 to 1994. Between 1994 and 1999, he worked as a research assistant at the University of Hawaii. He developed a coupled hurricane-ocean model system and proposed a new diagnostic approach to quantitatively assess contributions of various physical processes to tropical cyclone motion. As an AIRS data specialist from 2000 to 2001, he developed the official AIRS data support Web site and various tools for accessing Aqua AIRS data at the GSFC DAAC. Dr. Wu's current research interests includes tropical cyclone genesis, structure, intensity, and motion; air-sea interactions; numerical modeling; analysis and application of remote sensing data; and the relationship between climate changes and hurricane activities.

Dr. Yihua Wu received his B.S. degree in agrometeorology from Nanjing Institute of Meteorology in China in 1982, a M.S. in horticultural sciences, and a Ph.D. in atmospheric sciences from North Carolina State University in 1993 and 1997, respectively. From 1982 to 1992 he worked as an engineer at the National Meteorological Administration (NMA), China. Dr. Wu's major professional activities included research on modeling crop growth and development, and management of the national operation system of agrometeorological monitoring, information, and forecast. He won an award from National Meteorological Administration (NMA) for his contributions in promoting science and technology. He developed the real-time mesoscale model version 5 (MM5) Mesoscale Environment Forecasting System over the Southeast U.S., and was awarded Cray Fellowship when he did his postdoctoral work at the North Carolina State Climate Office in 1998. Dr. Wu developed a multiplayer biochemical dry deposition model when he worked as a visiting scientist at University Corporation for Atmospheric Research/U.S. Environmental Protection Agency from 1999 to 2002. His recent research interests have included atmospheric dynamics, mesoscale modeling, dry deposition modeling, and atmosphere-biosphere interactions.

Dr. Fanglin Yang is an assistant research scientist at GEST. He received a B.S. degree in 1989 and a M.S. in 1992, both in meteorology in China. Starting in 1994, he spent almost six years at the University of Illinois at Urbana-Champaign, working as a research assistant while pursing a Ph.D. degree in atmospheric sciences. After receiving his doctorate in 1999, Dr. Yang moved to Washington, D.C. and worked at the National Centers for Environmental Prediction for three years. He joined the Climate and Radiation Branch at GSFC in December 2002, under the auspices of GEST. Dr. Yang's research focuses on climate modeling and diagnosis, using atmospheric and oceanic general circulation models (GCMs) as the principle tool, supplemented by statistical methods and low-dimensional numerical models. His past research covers investigations of radiative forcing and climate changes induced by volcanic aerosols and greenhouse gases, development of atmospheric GCMs, and prediction and diagnosis of climate on seasonal-to-interannual time scales, forced by anomalous boundary conditions associated with sea surface temperature (SST), snow, and soil moisture. His current research focuses on trends and variability in East

Asian monsoonal precipitation. Dr. Yang is a member of the American Geophysical Union. He has served as a reviewer of articles for many professional journals.

Dr. Kao-San Yeh (also known as Kevin Yeh) has been an assistant research scientist at GEST since December 2001. He has developed numerical methods for modeling geophysical fluid dynamics since he joined GEST, including the Streamline Subgrid Integration method for applications on arbitrary grid systems. Dr. Yeh received a B.S. in physics from the National Taiwan University in 1987, an M.S. in mathematics from Purdue University in 1992, and a Ph.D. in meteorology, also from Purdue University, in 1997. He conducted the development of the nonhydrostatic version of the Canadian Global Environmental Multiscale Model as a postdoctoral appointment in the Meteorological Research Branch of Environment Canada in 1997-1999. From 1999-2001, Dr. Yeh generalized the NASA/ National Center for Atmospheric Research (NCAR) finite-volume General Circulation Model (fvGCM) from uniform to variable resolution as a research associate in the Earth System Science Interdisciplinary Center of the University of Maryland, College Park.

Dr. Boris S. Yurchak received a M.S. in electronics from the Kharkov Institute of Radioelectronics, USSR in 1969, and a Ph.D. in geophysics (physics and mathematics) in 1980 from the Institute of Experimental Meteorology, Goskomhidromet (the USSR Weather Service), Obninsk. His major research interest was application of radar methodology to cloud and precipitation measurements and atmospheric diffusion. From 1969 to 1996, Dr. Yurchak served as a research scientist and senior research scientist at the Institute of Experimental Meteorology, developing radar methodology for atmospheric research. From 1996 to 2001, he served as a senior research scientist and branch head at the Russia Federal Environmental Emergency Response Center (FEERC), Obninsk, Russia, where he developed a remote system for detecting clouds of pollutants in emergency situations. He also used remote sensing capabilities to study environmental contamination. In July 2002, Dr. Yurchak joined Caelum Research Corporation and started working on NASA's Earth Science and Public Health Program. Dr. Yurchak has been with GEST since July 2002. In June 2003, he joined UMBC**,** where he continued working on NASA's Earth Science and Public Health Program. His current research interests include remote sensing applications for public health issues in the Arctic.

Dr. Ilya Zavorin received his B.S. degree in mathematics and computer science from Santa Clara University in 1993 and his M.A. in applied mathematics from the University of Maryland, College Park (UMCP) in 1997. In August 2001, he completed the Ph.D. degree in applied mathematics from UMCP, where his research topic was convergence of iterative methods applied to large sparse linear systems. He has been involved with GSFC since 1998, working on the use of wavelets for automatic image registration of multi-sensor data. His current research interests also include optimization methods for image registration and automatic region-of-interest extraction.

Dr. Xiping Zeng received his B.S. and M.S. degrees in atmospheric physics from Nanjing Institute of Meteorology, China, and taught and performed research on clouds in that university from 1987 to 1995. In 1995, he began his doctoral studies in the Physics Department of the New Mexico Institute of Technology, focusing on the interactions between tropical convection and synoptic large-scale circulations. After receiving his degree he continued his work as a postdoctoral research physicist, and then joined GEST as a research associate. He collaborates with scientists at GSFC, upgrading a cloud-resolving model for explicit simulation of interactions between clouds and other factors (*e.g.,* aerosols, radiation, and synoptic large-scale circulations). Dr. Zeng serves as a reviewer for the *Journal of the Atmospheric Sciences* and the *Journal of Fluid Mechanics*.

Dr. Xiwu Zhan received his B.S. and M.S. degrees in meteorology from the Nanjing Institute of Meteorology. He then taught courses and conducted research in applied meteorology at the Institute. In 1990, he started his Ph.D. work at Cornell University on sensitivities of land surface water vapor fluxes to

atmospheric CO_2 increases at leaf, canopy, and regional scales. He continued this modeling study at the Hydrology Laboratory of the USDA-Agricultural Research Service from 1994 to 1996, after which he joined the geography research faculty at the University of Maryland, College Park, where he managed a research team and developed a set of change detection algorithms and the computer software of the Moderate Resolution Imaging Spectroradiometer (MODIS) 250-m land cover change product as an associate member of NASA's MODIS science team. Before he joined the GEST research faculty in 2002, he worked with the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Visible Infrared Imager Radiometer Suite (VIIRS) product algorithm development team at Raytheon ITSS Corporation. Dr. Zhan's current research interests include land surface energy and CO_2 flux modeling; generation of remote sensing data product of land surface soil moisture, temperature, and vegetation type; and assimilation of these data products into land surface models for better forecast accuracy of climate, hydrological, and/or ecological models.

Dr. Yunhe Zhao received a B.S. degree in computational mathematics from Xiamen University, Xiamen, China in 1984, and both M.S. and Ph.D. degrees in mathematics from North Dakota State University, Fargo, ND in 1993 and 1997, respectively. He has been with Caelum Research Corporation since May 1997, and has worked on site at GSFC in the Oceans and Ice Branch as a contractor. He currently is a senior analyst and works in the GEST program under the auspices of Caelum Research Corporation. During his graduate study, Dr. Zhao performed research on numerical solution of boundary integral equations, numerical integrations of improper integrals, and wavelet analysis and its applications in the numerical solutions of integral equations. Since working on site at GSFC, he has worked on satellite ocean and sea ice remote sensing data analysis and image processing, especially on deriving sea ice motion and deformation in the Arctic using wavelet analysis method from SSM/I, NSCAT, QuikSCAT, SeaWinds, and AMSR-E data, and using the derived data sets to study sea ice dynamics and the effects of atmospheric circulations on sea ice motion and deformation.

Dr. Jerry Ziemke obtained a Ph.D. in physics from Iowa State University. He has over 40 publications, most of which are in refereed journals and most of these as first author. Dr. Ziemke originally came to GSFC in 1994 as a National Research Council (NRC) postdoctoral fellow, specializing in atmospheric composition and dynamics. Since arriving at GSFC, he has collaborated with scientists at GSFC and elsewhere on a large range of topics, but primarily in studies relating to atmospheric ozone. Since 1996, his main focus has been satellite retrieval of tropospheric ozone. He is currently an active science team member for both Total Ozone Mapping Spectrometer (TOMS) and Earth Observing System (EOS)-Aura Ozone Monitoring Instrument (OMI), and he contributes to Stratospheric Processes and their Role in Climate (SPARC), World Meteorological Organization (WMO), and United Nations Environment Program (UNEP) reports. In recent years, Dr. Ziemke has contributed significantly to developing algorithm schemes to derive tropospheric ozone from cloud slicing and residual methods from satellite data. Dr. Ziemke became an associate research scientist at GEST in March 2002.

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Acronyms and Abbreviations

Acronym/ Abbreviation	Expansion/Definition
2-D	two-dimensional
3-D	three-dimensional
4DDA	four-dimensional data assimilation
4DVAR	four-dimensional variational data assimilation
AAAI	American Association for Artificial Intelligence
AC	atmospheric correction
ACE	Atmospheric Chemistry Explorer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADAM	Asian Dust Above Monterey
ADMAP	Antarctic Digital Magnetic Anomaly Project
AEJ	African Easterly Jet
AERI	Atmospheric Emitted Radiance Interferometer
AEROCAN	Aerosols in Canada Network
AEROCOM	Aerosol Model Intercomparison Project
AERONET	Aerosol Robotic Network
AEW	African easterly waves
AFWA	Air Force Weather Agency
AGCM	atmospheric general circulation model
AGRMET	Agricultural Meteorology modeling system
AGU	American Geophysical Union
AI	aerosol index
AIRS	Advanced Infrared Sounder
AISRP	Applied Information Systems Research Program
ALMA	Assistance for Land Modeling Activities
AMF	air mass factor
AMIP	Atmospheric Model Intercomparison Project
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
AO	Announcement of Opportunity
AO	Arctic Oscillation
AOD	aerosol optical depth
AOL	Airborne Oceanographic Lidar
APS	American Physical Society
ARCUS	Arctic Research Consortium of the United States

Acronym/ Abbreviation	Expansion/Definition
ARENA	Advanced Resources Evaluation and Networking Area
ARM	Atmospheric Radiation Measurement
ASCI	Advanced Strategic Computing Initiative
ASF	Alaska Satellite Facility
ASHE	Atlantic Seeding Hurricanes Experiments
ASLO	American Society of Limnology and Oceanography
ASTER	Advanced Spaceborne Thermal and Emissions Radiometer
ASU	Arizona State University
AVHRR	Advanced Very High Resolution Radiometer
AWARDS	Agricultural Water Resources Decision Support system
AWEX	AIRS Water Vapor Experiment
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BDRF	bidirectional reflectance function
BMC	Brazil-Malvinas Confluence
BMRC	Australian Bureau of Meteorology Research Centre
BOREAS	Boreal Ecosystem–Atmosphere Study
BRDF	bidirectional reflectance distribution function
BURST	Backup and Recovery Study Team
CAF	Co-Array Fortran
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection and Moisture Experiment
CAN	Cooperative Agreement Notice
CaPE	Convective and Precipitation-Electrification Experiment
CAR	Cloud Absorption Radiometer
CART	Clouds and Radiation Testbed
CAS	Chinese Academy of Sciences
casa	Carnegie-Ames-Stanford Approach
CAWSES	Climate And Weather of the Sun-Earth System
CCCma	Canadian Centre for Climate Modeling and Analysis
CCD	charge-coupled device
CCD	Convective Cloud Differential
CCM3	Community Climate Model version 3
CCRI	Climate Change Research
CCS	Central Computing System
CCSM	Community Climate System Model
CCSP	Climate Change Science Program

Acronym/ Abbreviation	Expansion/Definition
CDC	Climate Diagnostics Center
CEA	Commissariat à l'Energie Atomique
CENR	Committee on Environment and Natural Resource's
CEOP	Coordinated Earth Observing Period
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System
CES	Climate and Environment System Research Center
CESDIS	Center for Excellence in Space Data and Information Science
CG	conjugate gradient
CHAMP	Challenging Mini-Satellite Payload
Chl-*a*	chlorophyll *a*
Chl-*b*	chlorophyll *b*
Chl-*c*	chlorophyll *c*
CICEET	Cooperative Institute for Coastal and Estuarine Environmental Technology
CLAES	Cryogenic Limb Array Etalon Spectrometer
CLAMS	Chesapeake Lighthouse and Aircraft Measurements for Satellites
CLIVAR	Climate Variability and Predictability
CLM	Community Land Model
CLPE	Cold Lands Processes Experiment
CLPX	Cold Lands Processes Field Experiment
CMAP	Climate Prediction Center Merged Analysis of Precipitation
CMC	Canadian Meteorological Center
CNRS	National Center for Scientific Research (France)
COAA	Coastal Ocean Assessment and Analysis
COARE	Coupled Ocean-Atmosphere Response Experiment
COLA	Center for Ocean-Land-Atmosphere Studies
CONUS	Continental United States
COP	Conference of Parties
CoSSIR	Conical Scanning Submillimeter-wave Imaging Radiometer
COVE	CERES Ocean Validation Experiment
CPC	Climate Prediction Center
CPL	Cloud Physics Lidar
CPRS	Cloud Profiling Radar System
CPT	Climate Process Team
CPU	central processing unit
CRM	cloud-resolving models
CRS	Cloud Radar System

Acronym/ Abbreviation	Expansion/Definition
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers – Florida Area Cirrus Experiment
CT	Computational Technologies
CTM	chemistry and transport model
CU CFH	University of Colorado Cryogenic Frost point Hygrometer
CVS	Concurrent Versions System
CZCS	Coastal Zone Color Scanner
DAAC	distributed active archive center
dAMF	Differential (or Altitude-Dependent) Air Mass Factor
DAO	Data Assimilation Office
DAS	Data Assimilation System
DMSP	Defense Meteorological Satellite Program
DOAS	Differential Optical Absorption Spectroscopy
DoC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DSD	drop-size-distribution
DSS	decision support systems
DSTI	Decision Systems Technologies, Inc.
ECMWF	European Centers for Medium Range Weather Forecasts
EDOP	ER-2 Doppler Radar
EDR	Environmental Data Records
EDU	Engineering Development Unit
EKF	extended Kalman filter
EMC	Environmental Modeling Center
EnKF	ensemble Kalman filter
ENSO	El Niño/Southern Oscillation
ENVI	Environment for Visualizing Images
EOF	empirical orthogonal function
EOS	Earth Observing System
EPA	Environmental Protection Agency
ERBS	Earth Radiation Budget Satellite
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESE	Earth Science Enterprise
ESMF	Earth System Modeling Framework
ESS	Earth and Space Science

Acronym/ Abbreviation	Expansion/Definition
ESSP	Earth System Science Pathfinder
ESTEC	European Space Research & Technology Centre
ESTO	Earth Science Technology Office
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Meteorological Satellite
EUV	extreme ultraviolet
EVE	Educating with Virtual Experience
FAO	Food and Agricultural Organization
FAROP	Forecast of Atmospheric Radiative and Optical Properties
FAS	Foreign Agricultural Service
FCAR	Fonds pour la Formation de Chercheurs et l'Aide Recherche
FCN	free core nutation
FCRN	Fluxnet-Canada Research Network
FEERC	Federal Environmental Emergency Response Center
FEM	fluorescence emission
FEWSNET	Famine Early Warning Systems Network
FEX	fluorescence excitation
FIA	Forest Inventory and Analysis Program
FIRE	First ISCCP Regional Experiment
FIS	Friends of Information Science
FIT	Fizeau Interferometer Testbed
FPAR	fraction of photosynthetically active radiation
fvDAS	finite volume Data Assimilation System
fvGCM	finite-volume General Circulation Model
GAPP	GEWEX Americas Prediction Project
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCE	Goddard Cumulus Ensemble
GCM	general circulation model
GCMIII	third-generation general circulation model
GCMIII/CAM	Canadian Global Climate model/Canadian Aerosol Module
GCOS	Global Climate Observing System
GCRP	Global Change Research Program
GCSS	Global Cloud Systems Studies
GDAS	Global Data Assimilation System
GDS	GrADS-DODS Server
GEIS	Global Emerging Infections System

Acronym/ Abbreviation	Expansion/Definition
GEIS	Global Emerging Infections System
GEM	global environmental multiscale
GEM-AQ	GEM Canadian air quality model
GEMS	Global Environmental Monitoring System
GEOS	Goddard Earth Observing System
GEOSS	Global Earth Observation System of Systems
GEWEC	Global Water and Energy Cycles Program
GEWEX	Global Energy and Water Cycle Experiment
GF	globalization framework
GFDL	Geophysical Fluid Dynamics Lab
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GGP	Global Geodynamics Project
GHCN	Global Historical Climatology Network
GIMMS	Global Inventory Mapping and Monitoring Studies
GIRAS	Geographic Information Retrieval and Analysis System
GIS	Geographic Information Systems
GISS	Goddard Institute for Space Studies
GLACE	Global Land-Atmosphere Coupling Experiment
GLAS	Geoscience Laser Altimeter System
GLDAS	Global land Data Assimilation System
GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GMU	George Mason University
GOCART	Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GONG	Global Oscillations Network Group
GPCP	Global Precipitation Climatology Project
GPCTM	Goddard Parameterized Chemistry and Transport Model
GPM	Global Precipitation Measurement
GPP	gross primary productivity
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GrADS-DODS	Gridded Analysis Display System-Distributed Oceanographic Data System
GSRP	Graduate Student Researchers Program

Acronym/ Abbreviation	Expansion/Definition
GSWP-2	Global Soil Wetness Project Phase 2
GWC	Global Water Cycle
GWD	gravity wave drag
GWEC	Goddard Water and Energy Cycle
HALOE	Halogen Occultation Experiment
HIRS	High-resolution Infrared Radiation
HPCC	high-performance computing and communication
HPLC	high-performance liquid chromatography
HSPF	Hydrological Simulation Program–Fortran
HYCOM	Hybrid Coordinate Ocean Model
HYDROS	Hydrosphere State Mission
IAEA	International Atomic Energy Agency
IAI	Inter-American Institute
ICCP	International Commission on Clouds and Precipitation
ICESat	Ice, Cloud, and land Elevation Satellite
ICTP	International Center for Theoretical Physics
IDS	Interdisciplinary Science
IEEE	Institute of Electrical and Electronics Engineers
IGBP	International Geosphere-Biosphere Program
IGES	Institute for Global Environment and Society
IGOS	Integrated Global Observing Strategy
IHOP	International H_2O Project
IIT	Indian Institute of Technology
ILAS/ADEOS	Infrared Limb Atmospheric Spectrometer/Advanced Earth Observations Satellite
ILWS	International Living With a Star
IOP	Intensive Observations Period
IPC	interpolation and profile correction
IPCC	Intergovernmental Panel of Climate Change
IPGS	Institut de Physique du Globe de Strasbourg
IPO	Integrated Program Office
IR	infrared
ISCCP	International Satellite Cloud Climatology Project
ISIR	Infrared Spectral Imaging Radiometer
IST	ice surface temperature
ITCC	Information Technology and Computing Conference
ITCZ	intertropical convergence zone

Acronym/ Abbreviation	Expansion/Definition
IWG	Investigator's Working Group
JCET	Joint Center for Earth Systems Technology
JCSDA	Joint Center for Satellite Data Assimilation
JPL	Jet Propulsion Laboratory
KNMI	Royal Dutch Meteorological Institute
KWAJEX	Kwajalein Experiment
LAI	leaf area index
LASP	Laboratory of Atmospheric and Space Physics
LBA	Large-Scale Biosphere Atmosphere Experiment in the Amazon
LBA-ECO	LBA Ecological Research program
LBL	line-by-line
LCLUC	Land Cover-Land Use Change
LDAS	Land Data Assimilation System
LEARNERS	Leading Educators to Applications, Research, and NASA-related Educational Resources in Science
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LEEM	Laser Excitation/Emission Matrix Fluorometer
LEISA	Linear Etalon Imaging Spectral Array
LIS	Land Information System
LPA	Laser Phytoplankton Analyzer
LPT	Learning Technology Products
LSM	Land Surface Model
LSMA	Linear Spectral Mixture Analysis
LST	land surface temperature
LTER	Long Term Ecological Research
LUT	lookup table
MAX-DOAS	Multi-axis Differential Optical Absorption Spectroscopy
McRAS	Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme
MCS	mesoscale convective systems
MCST	MODIS Characterization Support Team
Metflux	micrometeorological-energy flux
MGS	Mars Global Surveyor
MHD	magnetohydrodynamic
MI	Microwave Imager
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MIRSL	Microwave Remote Sensing Laboratory
MISR	Multiangle Imaging Scanning Radiometer

Acronym/ Abbreviation	Expansion/Definition
MIT	Massachusetts Institute of Technology
MITB	Microwave Instrument Technology Branch
MJO	Madden-Julian Oscillation
MLO	Mixed Layer Ocean
MLS	Microwave Limb Sounder
MM5	Community Mesoscale Model version 5
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Orbiter Laser Altimeter
MOPITT	Measurement of Pollution in the Troposphere
MOU	Memoranda of Understanding
MPCM	Multistage Pulse Code Modulation
MPI	Message-Passing Interface
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
MPP	massively parallel programming
MRPV	Modified Rahman-Pinty-Verstraete
MSC	Meteorological Services of Canada
MSU	Moscow State University
NAAPS	Navy Aerosol Analysis Prediction System
NACP	North American Carbon Program
NalC	North American Landscape Characterization
NAO	North Atlantic Oscillation
NAS	National Academies of Sciences
NASDA	National Space Development Agency
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDVI	normalized difference vegetation index
NES	NASA's Education Enterprise Explorer Schools
NESDIS	National Environmental Satellite, Data, and Information Service
NEWS	NASA Energy and Water Cycle Study
NEXRAD	Next-Generation Radar
NEXT	NPP Engineering Development Unit Data Exchange Project
NGST	Northrop Grumman Space Technologies
NH	Northern Hemisphere
NLDAS	National Land Data Assimilation System
NMA	National Meteorological Administration
NMS	Nonhydrostatic Mesoscale Model

Acronym/ Abbreviation	Expansion/Definition
NOAA	National Oceanic and Atmospheric Administration
NOAH	NCEP/Oregon State University/Air Force/Office of Hydrology
NOGAPS	Navy Operational Global Atmospheric Prediction System
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPOL	NASA Polarimetric Radar
NPP	NPOESS Preparatory Project
NRA	NASA Research Announcement
NRC	National Research Council
NRL	Naval Research Laboratory
NSERC	National Sciences and Engineering Research Council (Canada)
NSF	National Science Foundation
NSIPP	NASA Seasonal-to-Interannual Prediction Project
NTU	National Taiwan University
NWS	National Weather Service
ODA	ocean data assimilation
ODE	ordinary differential equations
OGCM	ocean general circulation model
OI	optimal interpolation
OLR	outgoing longwave radiation
OLS	Operational Line-scan System
OMB	Office of Management and Budget
OMI	Ozone Monitoring Instrument
ONR	Office of Naval Research
OPO	optical parametric oscillator
OpTRAN	Optical Path Transmittance Model
OSA	Optical Society of America
Ostp	Office OF Science and Technology Policy
P&P	pump-and-probe
P2P	peer-to-peer
PAM	Portable Automated Mesonet
PARABOLA	Portable Apparatus for Rapid Acquisition of Bidirectional Observation of the Land and Atmosphere
PBL	planetary boundary layer
PBMR	Push Broom Microwave Radiometer
PC	principal component
PCA	principal component analysis
PDF	probability density function

Acronym/ Abbreviation	Expansion/Definition
PDO	Pacific Decadal Oscillation
PECAD	Production Estimation and Crop Assessment Division
PERSIANN	Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks
PMM	Purdue Mesoscale Model
PNA	Pacific-North American
POAM	Polar Ozone and Aerosol Measurement
POGO	Polar-Orbiting Geophysical Observatory
POM	Princeton Ocean Model
PR	Precipitation Radar
PRCM	Purdue Regional Climate Model
PREP	Principles of Remote Exploration
PRESTROM	Preliminary Regional Experiment for Storm-scale Operational and Research Meteorology
PRI	photosynthetic stress index
PRIDE	Puerto Rico Dust Experiment
PRT	physical radiative transfer
PSC	photosynthetic carotenoids
PSF	point-spread function
PSPT	Precision Solar Photometric Telescopes
PV	potential vorticity
QBO	Quasi-biennial oscillation
QPF	qualitative precipitation forecasting
ReSTS	Reanalysis for Stratospheric Trace gas Studies
RF	radio frequency
RMS	root-mean square
RMSE	root-mean square error
Rn	radon
RSB	reflected solar bands
RSM	regional spectral model
RSS	Remote Sensing Systems, Inc.
RSSIPL	Remote Sensing Signal and Image Processing Laboratory
RT	radiative transfer
RTM	River Transport Model
RVF	Rift Valley fever
SAC-C	Satellite de Aplicaciones/Cientifico-C
SAFARI	Southern African Regional Science Initiative

Acronym/ Abbreviation	Expansion/Definition
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	synthetic aperture radar
SBIR	Small Business Innovation Research
SBUV	Solar Backscatter Ultraviolet
SBUV/2	Solar Backscatter Ultraviolet Radiometer/2
SCAR-B	Smoke, Clouds, and Radiation Experiment in Brazil
SCO	stratospheric column ozone
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SCS	South China Sea
SCSMEX	SCS Monsoon Experiment
SDSM&T	South Dakota School of Mines and Technology
SEAM	South East Asian Monsoon
SeaWiFS	Sea-viewing Wide Field-of-View Sensor
SEM	Solar Extreme Ultraviolet Monitor
SERT	STEM Education Research and Technology
SGM	Science Goal Monitor
SGP	Southern Great Plains
SGS	subgrid scale
SH	Southern Hemisphere
SHADOZ	Southern Hemispheric Additional Ozonesondes
SI	Stellar Imager
SIB	Simple Biosphere Model
SIM	Spectral Irradiance Monitor
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies
SIO	Scripps Institution of Oceanography
SIPS	Science Investigator-led Processing System
SLAM	Small Lidar Advanced Measurement
SLF	Shipboard Laser Fluorometer
SMARTS	Small and Moderate Aperture Research Telescope System
SMMR	Scanning Multichannel Microwave Radiometer
SOA	State Oceanic Administration
SOHO	Solar and Heliospheric Observatory
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SOLSTICE	Solar-Stellar Irradiance Comparison Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SPARC	Stratospheric Processes and their Role in Climate

Acronym/ Abbreviation	Expansion/Definition
SPOT	Systeme Probatoire pour l'Observation de la Terre
SRL	Scanning Raman Lidar
SRT	surface return technique
SRTM	Shuttle Radar Topography Mission
SSB	sea-state bias
SSG	Science Steering Group
SSHA	sea-surface height anomaly
SSI	Streamline Subgrid Integration
SSM	Site Specific Measurement
SSM/I	Special Sensor Microwave/Imager
SSS	sea surface salinity
SST	sea surface temperature
SSULI	Special Sensor Ultraviolet Limb Imager
SSURGO	Soil Survey Geographic
START	System for Analysis, Research, and Training
STATSGO	State Soil Geographic
STE	stratosphere-troposphere exchange
STEM	science, technology, engineering, and mathematics
STTR	Small Business Technology Transfer
SVAT	Soil Vegetation Atmosphere Transfer
SVD	singular value decomposition
SVRN	Sufrace Reflectance Validation Network
SwASO	Southwestern and Southern Oceans
SWAT	Soil and Water Assessment Tool
SWE	snow water equivalent
SWH	significant wave height
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TCM3	Tropical Cyclone Model version 3
TCO	tropospheric column ozone
TDR	Time Domain Reflectivity
TEB	Thermal Emissive Bands
TEJ	Tropical Easterly Jet
TES	Tropospheric Emission Spectrometer
TIM	Total Irradiance Monitor
TK	Traditional Knowledge
TMI	TRMM Microwave Imager
TOGA	Tropical Ocean Global Atmosphere

Acronym/ Abbreviation	Expansion/Definition
TOMS	Total Ozone Mapping Spectrometer
TOS	The Oceanography Society
TOVS	TIROS Operational Vertical Sounder
TPW	total precipitable water
TRMM	Tropical Rainfall Measuring Mission
TSI	total solar irradiances
UARS	Upper Atmosphere Research Satellite
UAV	unmanned aerial vehicle
UCI	University of California, Irvine
UIBK	University of Innsbruck, Austria
UKMO	United Kingdom Meteorological Office
UMCP	University of Maryland College Park
UNCCD	United Nations Convention to Combat Desertification
UNCOPUOS/STSC	UN Committee on the Peaceful Uses of Outer Space/Scientific and Technical Subcommittee
UNEP	United Nations Environment Program
UNFCCC	UN Framework Convention on Climate Change
USAID	United States Agency for International Development
USAMRU	United States Army Medical Research Unit
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USRA	Universities Space Research Association
USTC	University of Science and Technology of China
USWCL	U.S. Water Conservation Lab
USWRP	U.S. Weather Research Program
UTC	Coordinated Universal Time
UV	ultraviolet
UWM	University of Wisconsin, Madison
VCD	vertical column density
VIIRS	Visible Infrared Imager Radiometer Suite
VIRGO	Variability Irradiance and Gravity Oscillations
VMR	Volume mixing ratio
VOAT	VIIRS Operational Algorithm Team
VWC	vegetation water content
WACAM	Whole Atmosphere Community Atmospheric Model

Acronym/ Abbreviation	Expansion/Definition
WatER	Water and Energy Research
WCP	World Climate Program
WCRP	World Climate Research Program
WHO	World Health Organization
WMO/GOS	Global Observing Systems' initiative of the World Meteorological Organization
WOUDC	World Ozone and UV Radiation Data Center
WRAIR	Walter Reed Army Institute for Research
WRF	Weather Research and Forecasting
WVT	water vapor tracer

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